Organising Knowledge in the Age of the Semantic Web: A Study of the Commensurability of Ontologies

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Declaration by the Candidate

I, Liam Magee, declare that:

a) except where due acknowledgement has been made, this work is that of myself alone;

b) this work has not been submitted previously, in whole or part, to qualify for any other academic award;

c) the content of the thesis is the result of work that has been carried out since the official commencement date of the approved research program;

d) any editorial work, paid or unpaid, carried out by a third party is acknowledged;

e) ethics procedures and guidelines have been followed.

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Abstract

This study is directed towards the problem of conceptual translation across different data management systems and formats, with a particular focus on those used in the emerging world of the Semantic Web. Increasingly, organisations have sought to connect information sources and services within and beyond their enterprise boundaries, building upon existing Internet facilities to offer improved research, planning, reporting and management capabilities. The Semantic Web is an ambitious response to this growing demand, offering a standards-based platform for sharing, linking and reasoning with information. The imagined result, a globalised knowledge network formed out of mutually referring data structures termed "ontologies", would make possible new kinds of queries, inferences and amalgamations of information. Such a network, though, is premised upon large numbers of manually drawn links between these ontologies. In practice, establishing these links is a complex translation task requiring considerable time and expertise; invariably, as ontologies and other structured information sources are published, many useful connections are neglected. To combat this, in recent years substantial research has been invested into "ontology matching"—the exploration of algorithmic approaches for automatically translating or aligning ontologies. These approaches, which exploit the explicit semantic properties of individual concepts, have registered impressive precision and recall results against humanly-engineered translations. However they are unable to make use of background cultural information about the overall systems in which those concepts are housed—how those systems are used, for what purpose they were designed, what methodological or theoretical principles underlined their construction, and so on. The present study investigates whether paying attention to these sociological dimensions of electronic knowledge systems could supplement algorithmic approaches in some circumstances. Specifically, it asks whether a holistic notion of commensurability can be useful when aligning or translating between such systems.

The first half of the study introduces the problem, surveys the literature, and outlines the general approach. It then proposes both a theoretical foundation and a practical framework for assessing commensurability of ontologies and other knowledge systems. Chapter 1 outlines the Semantic Web, ontologies and the problem of conceptual translation, and poses the key research questions. Conceptual translation can be treated as, by turns, a social, philosophical, linguistic or technological problem; Chapter 2 surveys a correspondingly wide range of literature and approaches.

The methods employed by the study are described in Chapter 3. Chapter 4 critically examines theories of conceptual schemes and commensurability, while Chapter 5 describes the framework itself, comprising a series of specific dimensions, a broad methodological approach, and a means for generating both qualitative and quantitative assessments.

The second half of the study then explores the notion of commensurability through several empirical frames. Chapters 6 to 8 applies the framework to a series of case studies. Chapter 6 presents a brief history of knowledge systems, and compares two of these systems—relational databases and Semantic Web ontologies. Chapter 7, in turn, compares several "upper-level" ontologies—reusable schematisations of abstract concepts like *Time* and *Space*. Chapter 8 reviews a recent, widely publicised controversy over the standardisation of document formats. This analysis in particular shows how the opaque dry world of technical specifications can reveal the complex network of social dynamics, interests and beliefs which coordinate and motivate them. Collectively, these studies demonstrate the framework is useful in making evident assumptions which motivate the design of different knowledge systems, and further, in assessing the commensurability of those systems. Chapter 9 then presents a further empirical study; here, the framework is implemented as a software system, and pilot tested among a small cohort of researchers. Finally, Chapter 10 summarises the argumentative trajectory of the study as a whole—that, broadly, an elaborated notion of commensurability can tease out important and salient features of translation inscrutable to purely algorithmic methods—and suggests some possibilities for further work.

Chapter 1

Introduction

> An ontology is an explicit specification of a conceptualization (Gruber, 1993, p. 199).
>
> Moreover, I have always disliked the word "ontology" (Hacking, 2002, p. 1).

This study is directed towards the problem of conceptual translation across data management systems, with a particular focus on those used in the emerging world of the Semantic Web. These systems are all too frequently characterised in essentialist terms—as through, as the etymology of "data" would suggest, they are merely the housing of neutral empirical givens. This study maintains, on the contrary, that systems always carry with them the assumptions of cultures who design and use them—cultures who are, in the very broadest sense, responsible for them. Together such assumptions make for a shared and accultured orientation towards some slice of the world; one which can be described as being more or less *commensurable* with other orientations held by other cultures. This feature of being "more or less commensurable"—of possessing varying degrees of cultural commensurability—can be exploited to guide the practical work of translating terms between knowledge systems. A low degree of commensurability exacerbates both the theoretical problem of semantic translation—how to translate concepts from one cognitive model to another—and the practical problem of data integration—how to move data from one physical system to another. Incommensurability of systems is not, though, taken here to be a fixed ontological divide which cannot be crossed; rather it is treated as an analytic category, as a measure of the work required to translate concepts from one system to another within an identifiable situational context. Two systems can be said to be *in*commensurable only when the estimate of this work fails some contextually-bound cost-benefit analysis or equivalent metric—when it proves to be impractical or infeasible for some expressly given purpose. Given some task of system translation, understanding before the fact the extent to which both the systems themselves, and the cultures responsible for them, are broadly commensurable ought to lead to better estimates of the scope of work involved in this translation. Principally, then, this study represents an effort to explore how to assess commensurability in practical situations; it does so by proposing a framework for that assessment, and applying it to a series of case studies. In addition, it endeavours to develop a robust theoretical foundation around the concept of commensurability, via a series of excursions into contemporary debates in philosophy, social theory and cognitive science.

The question of commensurability is asked here both of knowledge systems in general, and such systems as they are published on the Semantic Web in particular. The Semantic Web is an encompassing vision which imagines a network of connected, federated and integrated databases (Berners-Lee et al., 2001). It is motivated by the desire to simplify the integration of information from the myriad existing data sources and formats on the web. In the language of the Semantic Web, these structured data sets are termed *ontologies*, a co-opted piece of philosophical jargon describing how a region of the world is explicitly conceptualised in a series of codified commitments (Gruber, 1993). Semantic web ontologies use formal languages—the Resource Definition Framework (RDF) and Ontology Web Language (OWL)—to express these commitments (Berners-Lee et al., 2001). Because of the highly formal and explicit nature of these languages—relative to other approaches of representing knowledge—ontologies present good objects for studying the question of commensurability. While shared and standardised ontologies may simplify the job of system integrators connecting various data services over the Web, without explicit acknowledgement of the commensurability of their background assumptions, there remain significant impediments to the realisation of even a less ambitious variant of the Semantic Web. Adopting the standpoint that knowledge in the large is a culturally constructed and negotiated process, and so systems which codify knowledge can best be understood by interrogating that process, this study aims to find heuristic guidelines which can help determine, within a practical context, the extent of commensurability between such systems. This involves necessarily a more holistic orientation towards system design and integration than is usually applied within specifically computer science approaches to these problems, and so requires a broader lens, one which encompasses both the strengths and the complications of other disciplinary approaches.

Ontologies are taken here to be only an exemplary species of the broader genus of knowledge systems—a genus which can be extended to include other types of database models, XML schemas, expert systems and electronic classification systems generally. So while the focus is often directed towards Semantic Web ontologies, since they are not yet as commonly used in organisations as other types of systems, casting a broader net aims to extend the generality of the research findings without loss of semantic specificity. As the argument goes on to show, moreover, even the different formal properties of rival system types—Semantic Web ontologies compared with older database information models, for instance—can involve important assumptions of a philosophical ontological kind as well.

This study, then, argues that a holistic treatment of the commensurability of knowledge systems—both of the specific concepts, properties and relations they express, and of the broader cultural conceptualisations they imply or infer—can provide a useful heuristic guide to the practical translation and integration of such systems. Such a treatment, building upon both social and computer science disciplines, has an intended practical pay-off; it should augment existing, purely technical approaches to these problems.

The rest of this chapter is structured in three parts. The first part presents some brief historical context for the interest in knowledge systems—ontologies and databases—and situate the argument within a social theoretical framework. The second part introduces the core concepts and terms of the study, by introducing, in turn, the Semantic Web, ontologies, knowledge systems and the question of commensurability. The third part summarises the guiding research questions, purpose and structure of the work.

1.1 Putting Things in Order

In *The Order of Things*, Foucault (1970) writes of the "great tables of the seventeenth and eighteenth centuries, when in the disciplines of biology, economics and philology the raw phenomena of experience was classified, categorised, organised and labeled". At the start of the twenty-first century, when the classificatory technologies of the file system, spreadsheet, database and Internet search engine have superseded those of the ruler and pencil, these descriptions of "great tables" and their accompanying heroic taxonomic enterprises can seem quaint and anachronistic. The experience of lists, tables, hierarchical trees and networks and other informational structures as organisational aids is now unremarkable, quotidian, a tacit quality of a modern sensibility, reflected in the acquired facility to navigate everything from baroque scientific taxonomies and global standards to organisational directories and personalised databases. Consumers of electronic devices invest heavily in their repositories of music, books, photos and film, marking individual entries with qualifications of genre, commentary, ratings, biographical snippets and a host of other conceptual distinctions and demarcations. Business, governments and other organisations are necessarily technocratic taxonomists on a grand scale, investing in and managing large knowledge bases, processes, and infrastructure. Such fervent activity has even inspired the emergence of a dedicated industry and academic discipline—that of knowledge management. One of the fields of scientific enterprise Foucault himself analyses, biology, features ever-expanding databases of proteins, genomes, diseases and other biological entities, so vast in size that any single human attempt to review the data would fail by orders of magnitude (Arunguren, 2005). It is hard therefore to share Foucault's wonder at the ambition and scope of classical scholarship, without making an equally wondrously empathic leap back into the past. A modern-day reaction might instead regard these old classificatory systems as historical curiosities; at most, as experimental preludes, for better or worse, to the immense contemporary and global industries which serve an insatiable demand for information.

Yet our current age is also heir to the efforts of those classical scholars. Since Leibniz, the development of symbolic systems to represent knowledge has been a recurring motif of philosophy, and later, of other more applied disciplinary studies. From his universal symbolism, to Kant's categories, to Frege's descriptions of a formal logic, to the development of logical positivism in the 1920s, to, finally, the recent developments of the relational database, artificial intelligence and the Semantic Web, it is possible to trace a distinct and particular epistemological tradition. That tradition has sought to develop increasingly refined formal languages to represent statements about the world unambiguously. Rigorous empiricism—recording only observable facts—would, when coupled with an automatic deductive procedure based on a logical formalism, simplify the production of all knowledge to a series of mechanical acts. In Leibniz's famous dictum, once this point had been reached even philosophers would be able to settle arguments by appealing to machination: "Let us calculate!" (Lenzen, 2004).

There have been at least two notable impediments to the realisation of this vision up until the end of the twentieth century. The first is the development of feasible logic systems and technical implementations systems for representing these concepts. This has been the subject of considerable research and application in artificial intelligence, knowledge representation and broader information technology over the last fifty years. Such research, and the practical consequences of it, have produced in turn a series of pivotal technologies for the emergence of what Castells (1996) terms the "Network Society": the relational database—the current paradigmatic means for storing structured organisational information; the spreadsheet—a metaphor which pervades the construction of tabular data in the personal computing era; XML—a near-ubiquitous format for describing and transmitting data on the Internet; and semantic web ontologies, the emerging standardised mechanism for representing knowledge on the Internet.

The second impediment is development of consensual arrangements of concepts against which facts can be faithfully recorded. As the many successful cases of technical standards ratified by the ISO and other bodies show, there has been considerable success in efforts to develop standards. However, unlike the production of logical systems and implementations, consensus over such arrangements is frequently a brittle social dynamic, reliant upon what (Davidson, 2006) terms "the principle of charity" adopted between heterogenous cultures and actors, as they seek to exchange meaning with each other.

The development of computational classification systems and standards has experienced at least partial success because they facilitate a distinctly modern taxonomic impulse—an apparently unceasing desire to order, organised, catalogue, coordinate and control. What makes this desire distinctively modern? In response it could be argued, in a deflationary fashion, that the urge to put things in order is inherent in human language—nouns, and names particularly, express implicit taxonomies. However, natural languages are taxed with many functions other than that of articulating some state of affairs in the world—they must also issue imperatives, pose interrogatives, invoke vocatives and generally perform a host of more esoteric speech acts; and even in the case of assertoric utterances, they must also permit statement modulation according to tense, mood, aspect and a range of sociolinguistic inflections. In contrast, artificial formal languages are deliberately designed with both a minimal syntax—how statements can be expressed—and rigorous semantics—how those statements must be interpreted—in order to make electronic taxonomies easily constructible and unambiguously interpretable. These features are not coincidentally related to the rising informational needs of modern institutions, departments, bureaucracies and organisations. Indeed the tendencies of late capitalism suggest a self-reinforcing chain of multiple factors which stimulate this impulse towards order and categorisation: the operational benefits of the "network externalities" brought about by global communication networks; legal directives towards greater transparency and accountability; competitive pressures towards greater efficiencies; improved control and regulation both of people and objects, effected through ever more fine-grained classificatory structures. These factors both motivate and, in turn, are facilitated by the great affordances of information technology in the post-industrial era.

At the same time, the modernist conception of an organisation as a highly-regulated machine-like entity has been challenged by new, postmodern metaphors, which imagine the organisation as open, interconnected, self-reflexive, fluid, relational and networked (Ashkenas et al., 1995; Castells, 1996). The organisation is tasked with new, contemporary demands: to be visible, transparent, connected and accountable. It is to be audited regularly and stringently; it must be open to public inspection and accountable to numerous stakeholders—not only its direct constituents or shareholders, but a complex network of those with "stakes" in organisational governance and performance. It must also deal more directly with its members, constituents, customers, partners, employees, suppliers, regulatory bodies and press organisations, via a host of increasingly immediate, ubiquitous, connected and "on-demand" technologies. In the language of contemporary management rhetoric, an organisation must be open, porous, boundary-less (Ashkenas et al., 1995; Castells, 1996). Information is the pivotal part of this equation, the connection between modernist imperative to control, order and organise, and the postmodern desire to connect what is controlled, both within and between organisational boundaries. Accordingly, the desire to organise large amounts of information has led to interest, funding and prestige to be associated with information technologies, processes and management. These in turn have been seen as central to development of more successful organisations—organisations at any rate capable of greater performativity in a capitalistic environment. The twin development of the modern organisation and information technologies have been mutually reinforcing, to the extent that neither could any longer be imagined without the other. They are both features of a distinct phase of modernity.

Yet, just as these developments show a trend towards ever greater adoption of common, standardised and homogenised technical artefacts—informational and otherwise—they do not preclude an inverse tendency towards greater differentiation, in which various organisational cultures, brought into engagement within a globalised electronic landscape, both recognise and indeed actively produce perspectival differences towards the world they share. Like painters describing a landscape from different angles, these diverse orientations found both the conditions and limitations of the kinds of facts and observations which can be asserted about the world. Accumulating a base of information—a database—enables organisations rapid retrieval and analysis of data; yet the price of this is a certain rigidity or reification at work in the deployment of concepts used to structure the database. The record of a person in a database, for instance, captures only some facets, properties, attributes and variables about the person—those typically deemed salient for the use of the system. Moreover these properties "slice" the person in pre-defined ways, based on assumptions held by the culture responsible for the database. As the system is used over time, as more records are added, and other systems are adapted to fit the particular conceptualisation employed by the system, it becomes increasingly difficult to reengineer or "refactor" it. Consequently the conceptualisation becomes reified—appearing naturalised through the resilience to change of the system it is deployed in. Lost, or at least obscured, is the potential for other kinds of descriptions of entities to emerge. Nothing indicates, with the passing of time, that this is only one possible way among many others of "carving nature at its joints".

Viewed from the standpoints of either relativism or stark realism, this is either tautologically true or oxymoronically false—*true* if all expressions of facts are regarded as at best a partial and fragmentary glimpse of things as they are; *false* if some objective measure is accepted for why one concept is used instead of others. The objective here is to avoid any concomitant commitments along these metaphysical lines, but rather to recognise that in practice social convention determines a range of intermediate possibilities. To take one example, which is examined in further detail in one of the case studies: electronic documents are cultural objects which are described in a variety of ways—as official records in records management systems; as collectible items in bibliographic databases; as consumable objects in distribution systems like Amazon; as complex textual objects in word processing applications. All of these systems can be said to adopt a different standpoint—a metaphorisation of a different set of concepts and conceptual relations—of documents. Yet, equally, none of these views capture the *whole* truth of a particular document for its author (the possible difficulties of writing it), or a reader (the interpretive reading of it), or indeed the various features of a document required for many other purposes. Rather they capture the particular "facticities"—to employ a Foucauldian term—needed to exercise socially-instrumented practical functions around documents: to retrieve them, catalog them, edit them, print and bind them, distribute them, sell them, account for them, and so on. However, the conceptualisations engaged to describe documents for various functions are not at the same time discrete and self-contained bundles of properties or, in philosophical jargon, *qualia*, separate and unrelated to each other. To retain the geometric and spatial metaphor which is used throughout the study, conceptualisations frequently connect at orthogonal conceptual junctions and splices. They may share common concepts and properties—in the same example, books, authors and titles might be common terms across different system conceptualisations—and yet they may stand in different configurations and relations, which more or less line up depending upon the context of their translation and use. How to assess this "more-or-less-ness", the degree of *commensurability*, between the conceptual configurations operationalised by different systems, is then a question which information system "translators"—system analysts, engineers and programmers—increasingly face in a world where the prolixity of systems and the range of functions performed by them is ever-growing.

Between these opposing trends—towards standardisation, regulation, connectivity and unification on the one hand, and differentiation, customisation and individuation on the other—the promise of knowledge systems for these organisations has only been partially fulfilled. The digitisation of records managements, the development of sophisticated data warehousing tools, the agreement on protocols for transmission of data across networks—among other things—has led to vast increases of scale in the both the amount of data captured and the level of analysis which can be performed on this data. And yet here too, in the age of the Internet, the quantitative problems—cost and complexity—of communicating meaningful information across organisational boundaries have remained prohibitive, frustrating the aims of these very organisations. The Semantic Web is a technology platform explicitly designed to overcome the dilemmas of inter-system translation: a set of standards designed to allow translation and migration of data between systems and applications with the minimum of cognitive impedance or dissonance. Conceptual schemes are rendered as "ontologies", collections of concepts, properties and individual data records which can be developed using the existing technical infrastructure of the World Wide Web. Even here, however, interpretation, translation, coordination and negotiation of meaning cannot be relegated to the domain of purely technical and engineering considerations. While the systems themselves are technological artefacts, assessment of their commensurability leads from a concern over technical compatibility to broader questions of social meaning—what background cultural beliefs and practices motivate, justify and orient these systems? Along what dimensions can systems be said to be commensurable? What must be investigated, negotiated and made explicit in order for systems to be commensurable, translatable and interoperable? What elements of meaning might be sacrificed or abandoned in these negotiations? Together these questions compose a frame for exploring the central concern of this study—whether a holistic notion of commensurability, embracing both sociological and technological dimensions, can be usefully applied to the translation and coordination of organising schemes in the digital age.

1.2 Key Concepts—the Semantic Web, Ontologies and Commensurability

1.2.1 A Web of Meaning

The Semantic Web "provides a common framework that allows *data* to be shared and reused across application, enterprise, and community boundaries" (W3C, 2009b). It is constructed on the existing scaffolding of the World Wide Web: it makes use of the whole infrastructure of eXtended Mark-up Language (XML), Universal Resource Indicators (URI's) and to a degree, Hypertext Mark-up Language (HTML). The framework consists of two formal language specifications for making and connecting assertions about the world: the Resource Definition Framework (RDF) and Web Ontology Language (OWL). Several derivative standards describe rules, trust and proof conditions for reasoning and sharing the resulting assertional networks. Any system which supports these standards should be able to write and save data, which can in turn be processed and reasoned over by other compliant systems—bringing about, in theory, a level of interoperability not possible previously. Both RDF and OWL have been developed to be compatible with XML (eXtended Mark-up Language), another standard and common language for the encoding of data and documents (W3C, 2009a). One way of viewing the relationships between these standards is that XML supplies a standardised syntax, and RDF and OWL supply standardised semantics for data. Other syntaxes are also available for encoding RDF and OWL (Berners-Lee, 2009). However, widely available support, in the form of software tools and libraries, make XML a convenient choice for many purposes.

RDF is designed for describing resources—documents, images, audio and video files, as well as real-world objects which "can be *identified*"—on the web (Miller and Manola, 2004). Descriptions take the conventional logical form of *subject-predicate-object*, where the subject and object are generally identified via a web address, or more formally, a uniform resource identifier (URI). RDF does not supply an explicit vocabulary of terms such as "author", "publisher" or "creation date". Instead it operates at a higher level of abstraction, "specif[ying] mechanisms that may be used to name and describe properties and the classes of resource they describe" (Guha and Brickley, 2004). In other words, it provides well-defined abstract and formal structures—such as "class", "property", "string", "date" and "collection"—for composing such terms (Powers, 2003). OWL, in turn, extends RDF to handle descriptions of *ontologies*—a central concept for this study, which warrants a more extended introduction below. Together RDF and OWL form a basis for the standardisation of structured data on the Web, in such a way that both human and machine agents can share, query, navigate, manipulate and conduct inferences with it.

The Semantic Web is often explained in terms of consumer convenience. In a now famous statement heralding the advent of the semantic web, Berners-Lee et al. (2001) describe how it makes possible, for example, providing the ability to the aggregation of book catalogue records search across multiple websites for books, or the merging combining of contact information from one application with calendaring information data from another. The same article, written in the promissory and optimistic tones of technology evangelism, outlines how the semantic web will, more broadly, simplify the electronic life of a prototypical user:

> The semantic web will bring structure to the meaningful content of Web pages, creating an environment where software agents roaming from page to page can readily carry out sophisticated tasks for users. Such an agent coming to the clinic's Web page will know not just that the page has keywords such as 'treatment, medicine, physical, therapy' (as might be encoded today) but also that Dr. Hartman works at this clinic on Mondays, Wednesdays and Fridays and that the script takes a date range in yyyy-mm-dd format and returns appointment times. And it will 'know' all this without needing artificial intelligence on the scale of 2001's Hal or Star Wars's C-3PO. Instead these semantics were encoded into the Web page when the clinic's office manager (who never took Comp Sci 101) massaged it into shape using off-the-shelf software for writing semantic web pages along with resources listed on the Physical Therapy Association's site (Berners-Lee et al., 2001) .

Arguably, though, the semantic web has greater application to the costly problems of system integration which preoccupy organisational IT departments or enterprises: for example, how to get the accounts system to 'talk to' the human resources system, how to integrate two customer databases after a company merger, or how to represent transaction details across different national taxation regimes. These translation scenarios are common areas of complexity and cost in system integration, and stand to benefit from the kinds of interoperability at least promised by the semantic web. A key example of this use case has been the widespread adoption of the semantic web, and of ontologies in particular, among the bioinformatic research community.

It is worth adding here a cautionary note: in the decade since the early euphoric pronouncements of the semantic web, its adoption has been heavily fragmented. Research communities, such as those of the life sciences mentioned above, have been quick to embrace it. But the broader enterprise and consumer markets, targeted in the pitch cited above for instance, have stumbled over the apparent complexity and acronymic soup of its many recommendations and proposals. More specific causes have also been raised within the informal channels of the blogosphere (Shirky, 2003)—some of these are discussed in more detail in the comparison of knowledge systems in

Chapter 7, 'An historical introduction to formal knowledge systems'. Suffice to say, the degree to which the semantic web remains a research project, limited to scientific and academic applications, remains a highly contested issue. The recent more catholic usage of 'ontology', evident in the studies presented here, is indicative of more general desire to explore possibilities of many semantic webs, and many ontologies, inspired but not necessarily constrained to the specific proposals of the semantic web-in its proper noun form.

1.2.2 Ontology—Computing "What Is"

Before describing how ontologies are represented in OWL specifically, it is useful to describe the term "ontology" in its more general computer science usage. The term has been appropriated from its philosophical roots to describe knowledge systems. Despite the shift in meaning from its traditional moorings—where it is far from being an unambiguous term—this appropriation is not without basis: an ontology, for knowledge representation, is a series of statements which purport to describe how the world is. The canonical definition for computer science usage of "ontology" comes from Gruber (1993): "an ontology is an explicit specification of a conceptualization". Elsewhere he elaborates:

> Pragmatically, a common ontology defines the vocabulary with which queries and assertions are exchanged among agents. Ontological commitments are agreements to use the shared vocabulary in a coherent and consistent manner (Gruber, 1995, p. 909).

"Ontology" is therefore, even in its computer science usage, conceived in broad terms. In this study, it is generally treated as an umbrella term for a range of electronic classification systems: from those with minimal explicit semantics through to ontologies developed in OWL with a highly explicit semantics. It therefore includes taxonomies, controlled vocabularies, thesauri, classifications systems, catalogues, XML specifications, software designs, database and knowledge-base schemas, logical deduction systems and, finally, knowledge representation formats such as OWL. It is generally used interchangeably with the more descriptive term of "knowledge system", though sometimes it is employed specifically to differentiate Semantic Web ontologies from other kinds of knowledge systems—such cases should be clear from the context. "Information system" might equally serve this purpose; it has, however, a still broader designation, which includes software programs which may or may not actually store data, and which also have an executable component. Unlike programs, ontologies or knowledge bases do not generally contain procedures, though they may include rules which can be processed by programs.

1.2.3 Networked Ontologies—Towards the Semantic Web

A key goal of ontologies is that they are shared, re-useable repositories of data. In the short history of the Semantic Web a large number of ontologies have been developed for a range of fields and disciplines. Some of these ontologies define generic concepts, so-called "upper-level" or foundational ontologies. These are designed to be applied across many or all domains, and might include concepts such as `Process`, `Object`, `Time` and `Space`[1]. Others are quite specific to a given domain, such as the life sciences or linguistics. Upper-level ontologies can be incorporated or imported into more specific ontologies, which can be imported by other ontologies again—forming a lattice-like network of interconnected concepts. Ontologies which import other ontologies can also re-use their conceptual definitions, analogous to the world of object-oriented programming, where programming structures are re-used in a similar fashion (Booch et al., 2007). This is one way that concepts and data can be put towards purposes their original authors would not have envisioned. However, this relies upon explicit directives from the authors of the importing ontology, who also take responsibility for the explicit conceptual relations and translations they establish between their own and the imported ontology.

In other contexts, two ontologies which have been independently authored often need to be integrated, translated, aligned or merged. Developing points of connection between two ontologies can be a time-consuming and error-prone task, particularly if the ontologies are large—containing many concepts, relations or individual data records. A specific sub-disciplinary area, *ontology matching*, has been established to find automatic means of associating concepts from multiple ontologies. In addition to the explicit authoring of connections between ontologies described above, ontology matching holds promise for the explicitation of otherwise implicit connections between ontologies. Together these two approaches make it possible to envisage a global knowledge base—one of the declared aims of the Semantic Web. The literature review in Chapter 2 distinguishes several specific ontology matching approaches; in spite of these distinctions, though, the common underlying feature of these algorithms is the production of a set of individual concept matches. This set, referred to as an overall "alignment" of the ontologies (Shvaiko and Euzenat, 2005), can in turn be used to generate a translation from concepts in one ontology to concepts in another. Ignored in this translation process is the general degree of fit between the ontologies—how their overall conceptualisations are *commensurable*.

1.2.4 The Question of Commensurability

Commensurability as a concept originates in the field of geometry, meaning "of common measure". Wikipedia (2009), for example, defines this mathematical usage as follows: "If two quantities can be measured in the same *units*, they are commensu-

[1] Use of concepts in actual or hypothetical ontologies use a monospace font throughout the text.

rable". Kuhn, introducing the term to talk about scientific paradigms, describes it as follows:

> The hypotenuse of an isosceles right triangle is incommensurable with its side or the circumference of a circle with its radius in the sense that there is no unit of length contained without residue an integral number of times in each member of the pair.
>
> The incommensurability of these quantities does not mean one cannot be derived from the other however. In these two cases, hypotenuse = the root of 2 x side and circumference = 2 x PI x radius express the relations of these quantities. Since in both cases there is a residue, i.e. the equation does not result in an integer, the quantities are incommensurable (Kuhn, 1970, p. 189).

Kuhn (1970) makes use of commensurability as a metaphor for how scientific theories, "conceived of as sets of sentences, can be translated without residue or loss". Following Kuhn, I use the term "commensurability"—in place of synonyms like compatibility, congruence, or consistency—to connote a deeper level of cultural perspectival alignment between knowledge systems, while allowing for surface-level differences, such as differences in nomenclature. When faced with matching two ontologies, for instance, commensurability suggests there exists some deep conceptual equivalence between them, even if there are no shared terms or concepts. By contrast, *in*commensurability suggests substantial differences between their underlying cultural conceptions—differences requiring greater effort to effect translation between them. This study presents a similar argument to that of Kuhn's *Structure of Scientific Revolutions*: that semantic web ontologies and other formal representations of knowledge are not always commensurable, and that some form of social negotiation is needed to effect translation when this is the case.

Like scientific paradigms, ontologies can be treated as holding a particular orientation towards the slice of the world they describe. Such an orientation bears any number of assumptions which are properly *ontological* in the philosophical sense—assumptions about how the world is, derived from the cultural backdrop in which the orientation is formulated. Together these assumptions form the epistemic conditions under which ontologies—of the semantic web kind—can be developed. To give a hypothetical example which is explored further in the work as a case study: two separate ontologies could be developed to describe the world of documents. The first ontology uses the term `Author`, while the second ontology uses the alternative of `Collaborator`. `Author`s are people specifically engaged in the creation of the document—they write the text, capture and insert the images, structure the document and so on. `Collaborator`s have a looser relationship—they may edit, publish, translate, typeset or perform any number of other activities in relation to the document. At this stage—without further knowledge or recourse to context—it is possible to interpret the difference in at least two ways. On the one hand, the difference could be viewed as contingent and accidental—a question of near-synonymic variants. In the second case, a more general term was chosen, which includes the specific term of the first—all `Author`s are also `Collaborator`s. On the other hand, the difference could also mark a more fundamental ontological difference. Here, in the second ontology, there is no suitable translation for `Author`. Instead `Collaborators` simply collaborate to create a document—which could mean writing it, editing it, typesetting it, and so on. Indeed, possibly the concept of authorship is explicitly denied; there are no `Collaborator`s bearing the special distinction of authorship. The first interpretation suggests there is in fact some underlying commensurability between these ontologies, in spite of the different terms chosen. They share the same view of the world, in which documents have both `Author`s and `Collaborator`s, and `Author`s are particular kinds of `Collaborator`s. The second interpretation instead suggests that at least in relation to these particular concepts of the two ontologies, the question of translatability is ambiguous. Consequently, commensurability is a less settled question, requiring at the very least further supplementary information.

According to the literal meaning, it could be argued that all knowledge systems, insofar as they employ different conceptual schemes, are trivially incommensurable. In the sense used here, however, commensurability is a question of degrees rather than kind—what matters is the extent of difference, and by extension, the cost, time and effort of translation, between those systems. To assess this means going beyond the explicit representations of the systems themselves, inferring something about the implicit background network of assumptions which underpin them—variously termed their "world views", "conceptual schemes", "paradigms", "epistemes", "gestalts" or "frames of reference". This study aims to demonstrate that using the metaphor of commensurability is a helpful way to conceive of both the explicit and tacit differences in the design of knowledge systems; helpful insofar as it provides practitioners with ways of identifying and bridging those differences—or, just as importantly, identifying when such differences are not practically translatable. Here, incommensurability does not imply a slippery slope into relativism or solipsism—a world in which knowledge systems, no less than the cultures who construct and use them, forever remain trapped in their particular hermetic conceptualisations. On the contrary, proper analysis of ontologies can lead to productive insights into the sorts of differences between them, and whether such differences can be readily reconciled in a given situational context.

The question of commensurability is directed towards the same sorts of problems identified by field of ontology matching (Shvaiko and Euzenat, 2005). Ontology matching approaches seek to develop algorithms to match the terms of two or more ontologies, based on exploitation of terminological similarities. As discussed further in Chapter 2, concept-by-concept matches generated by these approaches are a necessary but insufficient means of solving certain problems of "semantic heterogeneity" (Shvaiko and Euzenat, 2005). The framework developed here is intended to augment these approaches by considering translation from a semantic holistic perspective—where not only individual conceptual matches but overall schematic commensurability can be assessed.

1.3 Research Questions

Having worked through some of the background concepts, the central research question organising the study can now be stated:

> Is the concept of "commensurability"—describing how electronic knowledge systems compare across a range of both sociological and technological dimensions—useful in guiding the alignment of these systems?

In order to answer this question, the study also poses and responds to a number of subsidiary questions:

> What sort of *theoretical apparatus* can be used to describe the commensurability of ontologies?
>
> What kind of *general purpose framework* might be developed for evaluating the commensurability of ontologies?
>
> How can the *usefulness* of the framework be assessed?
>
> Can the framework be applied to *current cases* of knowledge system commensurability?
>
> Can the framework be implemented as a *software system*, and used by others?

The scope and direction of the research questions, in seeking to direct attention towards the sociological and technological—and, at times, delving into the cognitive and linguistic—aspects of knowledge systems, requires the study to cross several disciplinary boundaries. At various points, the study adopts a range of perspectival "frames", shifting from an engineering orientation—looking at pragmatic trade-offs involved in the practices of designing, modelling and aligning systems—to a sociological or ethnographic one—looking at those practices from an estranged distance, observing them as rituals enacted within broader overlays of cultural significance and meaning. The interplay between these orientations bears witness to the complexities of navigating cultural boundaries which form the foundational concern of the work. In that sense the argument as a whole constitutes itself a kind of case study of the commensurability of different knowledge systems.

1.4 General Approach

To explore these questions, I first discuss literature from a range of sources taken from both technical and social scientific disciplines, and outline the general methodology adopted by the study. I then develop in more detail a theoretical discussion of cultural conceptual schemes, and suggest a general purpose framework for comparing them. The end result of the application of the framework ought to be detailed profiles of two knowledge systems under consideration, comparable both as technical objects and cultural artefacts. To evaluate the framework empirically, I apply the framework to three case studies, and describe a further pilot study in which the framework is operationalised in software for others to use. The findings, results, limitations and future considerations are discussed in the conclusion. A more detailed outline of the structure of the work is provided below.

1.4.1 Structure of the Work

Chapter 1, the present chapter, introduces the Semantic Web, ontologies and the question of ontology commensurability against a general background of the development of formal knowledge systems. The research questions of the study are posed here, and the general approach and structure is outlined.

Chapter 2 examines four strains of literature dealing with the broad theme of "semantics". By examining this theme through various disciplinary rubrics—of language, cognition, culture and computation—the specific concerns of knowledge system translation and alignment can be brought into a larger constellation of concerns with meaning generally. In the process several key concepts and specific dimensions relating to commensurability are teased out and analysed.

Chapter 3 describes both how the framework itself is evaluated in the study, and also what is meant by "methodology" in the context of the framework itself. Just how judgments about commensurability of ontologies are formed requires that the framework contain a methodological component, which suggests ways of knowing and understanding formal systems like ontologies much as one would a work of art or cultural artefact—as an object interpretable against the background conditions of its formulation and use. This chapter describes this aspect of the framework, but also how the framework as a whole is tested and evaluated in terms of its usefulness in assessing commensurability.

Chapter 4 examines part of the philosophical tradition dealing with what has been referred to here as perspectival assumptions, orientations or views, and some near-cognates such as paradigms, *epistemes* and conceptual schemes. Generally such terms are applied in the domains of the physical or human sciences, to describe discontinuities between historical periods, cultures and disciplines. Here these theoretical models are applied to knowledge systems such as ontologies and databases. Several criticisms of what is sometimes characterised as the Standard Social Sciences Model (Pinker, 1995), the view that we cannot escape our particular paradigms and schemes, are also acknowledged and discussed. This view can be further extended to suggest paradigms are *inescapably* incommensurable—a corrosive position from the standpoint of this study. I therefore work towards a modified version of this view, in which commensurability is an analytic assessment, not an ontological quality; this version is not incompatible with particular readings of Kuhn, Foucault and Quine developed here.

Having plotted out several formative theories of commensurability and conceptual schemas, several more recent cognitive, linguistic and social developments are then discussed—the social theory of Habermas, the pragmatic approach to language proposed by Brandom, and the work of Gardenfors on "conceptual spaces". These in turn form the basis for the framework proposed in the following chapter.

Chapter 5 builds on the previous chapter by proposing a framework for assessing commensurability in practice. The framework comprises of (a) a model of an ontology commensurability scenario; (b) a two-tiered series of dimensions for profiling ontologies; (c) a methodological outline for investigating the social context in which ontologies are developed and used, and for subsequently rating ontologies against dimensions; and (d) a basic mechanism for generating a quantitative assessment of ontological commensurability. The methodology comprises of two components: a technical analysis of ontologies, using various metrics such as size, complexity and scope; and a sociological exploration of purposes, motivations, practices and perspectives embodied in the ontologies, using light-weight adaptations of social research methods such as content analysis—of, for example, online forums, background publications and third-party commentary. As well as drawing out the assumptions of the ontologies, the aim of the framework is make explicit the value judgments and assumptions otherwise implicit in the evaluation process itself.

The subsequent three chapters (6 through to 8) develop case studies which apply the framework in different contexts: to different kinds of formal knowledge systems, upper-level ontologies, and document formats, respectively.

Chapter 6 develops a historical overview of the development of formal knowledge systems themselves, through investigations in formal logic in 19th and early 20th centuries; early database systems in 1960s and 1970s; dominance of relational model in 1980s and 1990s; and the emergence of Semantic Web in the past decade. Knowledge systems such as relational databases, XML schemas and Semantic Web ontologies each themselves have different histories and corresponding inflections on the question of how to represent concepts and objects. The general ontological assumptions of the relational model are contrasted with those of Semantic Web ontologies, in particular, and a general assessment of their commensurability is developed.

Another area of recent activity in knowledge representation has been the development of so-called "upper-level ontologies"—ontologies which describe abstract concepts such as `Process`, `Object`, `Time` and `Space`. Chapter 7 presents a case study of these ontologies. Authors working in this area have regarded upper-level ontologies as foundational for system interoperability at less abstract levels of representation, while others have advocated forms of ontological pluralism or agnosticism—again, this makes a useful case study for the application of the framework. In addition to an analysis of the ontologies themselves, I look at two online mailing lists, where some of the distinctions between these ontologies and the positions they entail are discussed in more detail.

The more concrete world of document formats is considered in Chapter 8. While document formats have not (yet) been specified using Semantic Web standards such as OWL and RDF—authors have used syntax-only standards such as XML instead—a recent controversy over document format standardisation provides an excellent setting for examining the economic, political and legal factors which influence the development of technology specifications and systems. The "real-politic" of standards development, in this case played out in very public fora, showcases questions of commensurability to which the framework can equally be applied.

Chapter 9, the penultimate chapter, discusses a software system which implements and operationalises the framework. This software was developed over the course of the study, and trialled to a pilot group at RMIT University. The process of software construction, and its subsequent evaluation, are discussed here. Where the preceding case studies represent examples of the framework applied by the researcher directly, the pilot study presents the software as an instrument to other researchers, with mixed results.

In Chapter 10, the conclusion brings together the various strands of the argument of the work, to make a case for the pragmatic usefulness of a theory and a framework of commensurability. Where the paradigmatic form of knowledge representation are Semantic Web ontologies—designed expressly for the sharing and reuse of knowledge in an interconnected world—understanding not only the explicit claims made by these systems, but also the implicit cultural orientations which underpin them, is of fundamental interest to the avowed aims of the Semantic Web. The conclusion also suggests ways in which the research can be furthered in future work, and potentially applied beyond this specific area of focus.

1.5 Towards a Framing of Semantics

The Semantic Web makes bold claims about solving problems of system interoperability — a "silver bullet" solution, in effect, for an industry in which software incompatibilities, project failures, patch-work solutions and "semantic heterogeneity" are sources of significant costs (Shvaiko and Euzenat, 2008). Moreover it provides a means for weaving together the rich tapestry of existing data on the Internet, by providing transparent means for making the structure of that data explicit. A subsidiary discipline has developed, *ontology matching*, which has sought various algorithmic solutions to the problem of integrating related ontologies. This study argues that translation in some contexts needs a holistic regard for the general cultural conceptualisations underpinning ontologies, which can usefully augment concept-by-concept matching algorithms. The Kuhnian term of *commensurability* is introduced in order to describe the overall degree of fit between two ontologies, assessed across a range of cognitive, social and technical dimensions.

The next chapter explores literature from a range of disciplinary perspectives that examine the question of conceptual commensurability through the very broad thematic frame of "semantics". This exploration also develops several general constructs and specific dimensions, which are then later organised within the framework in Chapter 5.

Chapter 2

Literature Review

> The sentence "Snow is white" is true if, and only if, snow is white (Tarski, 1957, p. 190).

The question of commensurability of Semantic Web ontologies and related knowledge systems raised in the introductory chapter can be explored from several disciplinary perspectives. A guiding thread through these frames is the very general notion of *meaning*—as something which can be variously reasoned over computationally, generated or processed cognitively, expressed linguistically and transmitted socially. The question of commensurability can be re-phrased in relation to meaning as follows: whether any two *systems of meaning*—combining units of meaning into a larger structural whole—can be related in a consistent, coherent and commensurate way. This study suggests that answering this question involves understanding the different registers or dimensions of meaning in which those systems can be located. The literature reviewed here discusses a number of these dimensions, which have been classified accordingly under the following "semantic" rubrics or frames:

- Linguistic Semantics
- Cognitive Semantics
- Social Semantics
- Computational Semantics

In addition to surveying some of the current research in these fields, this review also serves as a precursory schematisation of the kinds of variables used to organise, cluster and describe knowledge systems. Chapter 5 later presents a formal arrangement of these dimensions as part of a framework for assessing commensurability.

The first of the disciplinary frames surveyed below considers semantics as a subsidiary linguistics discipline—as the study of meaning as it is expressed in language. A general discussion outlines some of the major conceptual distinctions in this field. Given the reliance of knowledge systems on formal languages of different kinds, work in the area of formal semantics is discussed specifically. Other kinds of research have been directed towards the interpretation and use of ordinary everyday language—these theories in related fields of hermeneutics and pragmatics are also reviewed briefly.

Another, closely related frame concerns recent work conducted in cognitive science and psychology on concept formation, categorisation and classification. Examining recent models of cognition can provide clues as to possible causes and locations of incommensurability between conceptualisations made explicit in ontologies. Several recent theories have developed explicitly spatial models of mind and cognition, which provide helpful metaphorical support, at least, for a discussion of commensurability. A review of recent research in these fields is developed in the section on *Cognitive Semantics*.

As well as being amenable to algorithmic analysis, representations of cognitive phenomena, and linguistic artefacts, ontologies are also *social* products—they are things produced and consumed within a broader marketplace of communicative practices. It is then useful also to look at social theoretic models of communication generally, to see how these devolve on to the specific concerns of ontology commensurability. While Chapter 4 examines several social theorists in more detail, here it is useful to survey a range of both theoretical and empirical research conducted under the broad umbrella of the social sciences. Specifically, research in key fields—sociology of knowledge, studies of technology and science, knowledge management, research in IT standardisation and cross-cultural anthropology—help to introduce certain concepts which emerge again in the development of the commensurability framework in Chapter 5. A review of these fields is provided in the section on *Social Semantics* below.

Extensive research has been undertaken in the field of computer science, notably in the area of ontology matching but also in related areas of ontology and database modeling and design. Much of this research focusses on developing improved algorithms for concept translation between ontologies; as noted in the introduction, there has been relatively little attention to using background knowledge as a heuristic tool for augmenting ontology translation efforts. The section on *Computational Semantics*, below, surveys work in ontology matching, and also discusses related studies looking at ontology metrics and collaboration.

Finally, considerable work in philosophy of mind and language has been oriented towards problems of conceptual schemes, translatability and interpretation. However this field is much too broad to survey even schematically here; Chapter 4 does provide further review of this tradition, within the specific context of outlining a theoretical background for a framework of commensurability.

The trajectory plotted through this literature review, from the relationship of semantics to language, mind and society, through to the specific problems of ontology matching, moves in a somewhat spiral fashion: from broad down to narrow concerns. This order of presentation is then inverted by the presentation of ontology profiling dimensions in the framework discussion in Chapter 5, as narrow technical dimensions lead eventually to consideration of broader social ones.

2.1 Linguistic Semantics

2.1.1 Semantics in Language

As a subsidiary domain of linguistics, semantics is, as a recent textbook puts it, "the study of the systematic ways in which languages structure meaning" (Besnier et al., 1992). Early in the history of linguistics, Ferdinand de Saussure established several foundational semantic distinctions: between *signifier* (a spoken or written symbol) and *signified* (a mental concept); and between *sign* (the combination of signifier and signified) and *referent* (the thing referred to by the sign) (Saussure, 1986). Bloomfieldian research in the 1930s and 1940s emphasised structural, comparative and descriptive rather than semantic features of language; ironically it was the advent of Chomskyian generative grammar in the 1950s which, in spite of emphasising syntax, also paved the way for a more explicit focus on semantics in the 1960s (Harris, 1993). Since then, numerous kinds, branches and theories of semantics have emerged: generative semantics, formal semantics (applied to natural languages), lexical semantics, componential analysis, prototype and metaphor theories, "universal" semantics, cognitive semantics, hermeneutics, pragmatics and various theories of translation—not to mention the general interest in semantic computer applications and platforms such as the Semantic Web.

Linguistic meaning can be studied through several different lexical units or levels: words, sentences, groups of sentences, discourse or text, and a corpus of texts (Besnier et al., 1992). At each level, different types of meaning can also be distinguished. In the classical essay "Sense and Reference", Frege distinguishes what objects in the world words refer to—their extensional or denotative meaning—from how those words are defined by other words—their intensional or connotative meaning. More recent analyses of meaning build on this primary distinction; for example, Chierchia and McConnell-Ginet (2000) distinguish denotational (or referential) from both psychologistic (or mentalistic) and social (or pragmatic) theories of meaning, while Leech (1981) proposes a total of seven types of meaning: conceptual meaning, connotative meaning, social meaning, affective meaning, reflected meaning, collocative meaning, and thematic meaning. Denotational or conceptual meaning is regarded as primary in most mainstream semantic accounts; since this referring capacity of language is essential for other types of meaning to be possible, "it can be shown to be integral to the essential functioning of language in a way that other types of meaning are not" (Leech, 1981, p. 9).

Approaches to understanding natural language meaning even in a denotational sense vary considerably. Common approaches include componential analysis, where semantic units—typically, words—are given positive or negative markers against a set of "components" or "dimensions" of meaning (Burling, 1964; Leech, 1981); and lexical analysis, where relations of units to each other are defined according to a set of rules: synonymy/antonymy (units with the same/opposite meanings to other units); hypernymy/hyponymy (units which are superordinate/subordinate in meaning to other units); holonymy/meronymy (units which stand in relation of wholes/parts to other units); and homonymy/polysemy (units which have one/multiple definitions) (Besnier et al., 1992; Cann, 1993).

As an early critic of componential analysis noted, underlying "dimensions" of meaning are not immediately obvious—they need to be explicitly theorised (Burling, 1964). One effort to develop a core set of shared concepts which underpin *all* languages is Goddard and Wierzbicka's "natural semantic metalanguage" (NSM). The "metalanguage" proposes a highly abstracted lexical inventory of "semantic primes" from which all lexical units in any language can be derived (Goddard, 2002)—an idea which is related to Rosch's "basic" categories, discussed below. Generation of such primes requires a "trial-and-error" approach of postulating prime candidates (Goddard, 2002), and mapping their derivation from the metalanguage into various natural language forms (Goddard and Wierzbicka, 2002). As the authors suggest, the process is time-consuming and highly speculative; yet brought to fruition, would provide a powerful device for, among other things, providing unambiguous rules for the translation of concepts across natural languages (Wierzbicka, 1980). As the case-study on upper-level ontologies shows, the effort to develop a metalanguage for natural languages has its direct analogue in equivalent efforts to develop a set of foundational or core concepts for formal knowledge representations—with much the same difficulties and trade-offs.

The remainder of the review of linguistic approach to meaning moves in three directions, which roughly mirror the division suggested by Chierchia and McConnell-Ginet (2000): towards *formal* semantics, which seeks to describe meaning within a logic-based framework; towards hermeneutics, which understands meaning in a holistic and subjectively-inflected way; and towards pragmatics, which understands meaning as a kind of social practice. Each of these approaches has important implications for a theory of commensurability developed here, and while apparently contradictory, the aim here is instead to demonstrate broad lines of complementarity. As Chierchia and McConnell-Ginet (2000, p. 54) emphasise, in a related context:

> We believe that these three perspectives are by no means incompatible. On the contrary, meaning has all three aspects (namely, the denotational, representational, and pragmatic aspects). Any theory that ignores any of them will deprive itself of a source of insight and is ultimately likely to prove unsatisfactory.

What is "representational" here is also given more expansive treatment under

"Cognitive Semantics"; what is termed "pragmatic" is also discussed further under "Social Semantics". However, the hermeneutic and pragmatic traditions covered here provide the means for extending out from language towards those cognitive and social domains, and consequently provide important building blocks in the development of the theory of commensurability.

2.1.2 Formal Semantics

A significant strain of semantic research arose from work conducted in logic and foundational mathematics in the early twentieth century—a tradition touched on in more, albeit still schematic, detail in Chapter 6. Within this tradition, "semantics" is interpreted truth-functionally—a statement's meaning is just whether the proposition it expresses is true or false. Formal semantics arose generally through the interests of logical positivism, but specifically through an ingenious response to the logical paradoxes which had beset the preceding generation of logicians in the early twentieth century. Tarski's semantic conception of truth, first published in 1933, provided a "formally correct and materially adequate" basis for describing the truth conditions of a proposition (Hodges, 2008). One of Tarski's innovations was to impose a condition on a formal language, L, that it cannot construct a sentence based on an existing sentence and the predicate "is true"—such a sentence could only be constructed in a *metalanguage*, M, which contains all of the sentences of L and the additional "is true" predicate. Consequently, a paradoxical statement like "this sentence is false" becomes nonsensical—to make sense, it is split into two sentences, the first of which contains the sentence under consideration in the object language L, and the second of which defines the truth value of the first in the metalanguage, M (Hodges, 2008; Cann, 1993). For Tarski, at least, this conception could apply to the kinds of statements common to the sciences:

> At the present time the only languages with a specified structure are the formalized languages of various systems of deductive logic, possibly enriched by the introduction of certain non-logical terms. However, the field of application of these languages is rather comprehensive; we are able, theoretically, to develop in them various branches of science, for instance, mathematics and theoretical physics (Tarski, 1957, p. 8).

The formal semantic conception of truth strongly influenced Quine, Davidson and Popper, among others. Although directed specifically towards formal languages, Tarski's *Convention T* was applied first to natural languages by Davidson Davidson (2006). More systematic accounts of natural language as a derivative of formal logic, where sentential parts sit as truth-bearing components within a sentential whole, were developed by Tarksi's student Montague Montague (1974), followed by Dowty (1979), Partee (2004) and others (Kao, 2004). The guiding insight of formal semantics was the "principle of compositionality":

> The meaning of an expression is a monotonic function of the meaning of its parts and the way they are put together (Cann, 1993, p. 4).

While Chomsky's generative grammar demonstrated how sentences could be syntactically "put together", by the end of the 1960s rival generative (Lakoff, McCawley, Postal and Katz) and interpretivist (Jackendoff and Chomsky) semantic movements had as yet yielded no prevailing paradigm for accounting for how the meaning of sentential parts—individual words, as well as noun and verb phrases, for example—could account for the meaning of the sentence as a whole (Harris, 1993). Montague grammar sought to provide a unified theory for the syntax and semantics of both natural and artificial languages (Kao, 2004). In *The Proper Treatment of Quantification in Ordinary English*, the seminal account of such a theory, Montague presents a syntax of a fragment of English, a form of "tensed intensional logic" derived from Kripkean possible world semantics, and finally, rules for translating a subset of English sentences into the intensional logic. The role of the intensional logic is to handle certain classes of "complex intensional locutions", using "intensional verbs". For example, the truth value of a sentence containing the verb "seeks" can vary depending upon the verb complement—resolving the truth value means knowing the state of affairs which pertain within a possible world at a particular point in time (Forbes, 2008). By demonstrating how it was possible to translate a large group of natural language sentences into disambiguated propositions, analysable into parts with truth conditions and able to stand as premises in logical inferences, Montague opened rich possibilities for further research in formal semantics (Kracht, 2008; Partee, 2004).

Formal semantics inspired by Tarski's model theory has also been used in the construction of syntactically well-formed and semantically interpretable artificial languages for knowledge representation, including the languages of the Semantic Web, RDF (Resource Definition Framework) and OWL (Web Ontology Language) (Hayes, 2004; Hayes et al., 2004). The somewhat arcane origins of this "semantic" epithet—by way of the abstractions of model theory and description logics—has led, perversely, to several varying interpretations of the Semantic Web itself: as a process of incremental technological adaptation, or as a wholesale revolution of how knowledge is produced, represented, disseminated and managed. Both the development and subsequent interpretations of the Semantic Web are described in more detail in Chapter 6.

2.1.3 Hermeneutics and Semantics

Hermeneutics predates the scientific study of semantics described above by some historical distance, originating in German Enlightenment philosophy in the eighteenth and early nineteenth centuries (Mueller-Vollmer, 1988). Etymologically derived from the Greek for "translate" or "interpret", it is similarly concerned with meaning in a very general sense. In its earliest incarnations, the aims of hermeneutics were broadly sympathetic with later waves of the epistemologically ambitious programs of logical positivism and the Semantic Web:

> Finally, with the desire of Enlightenment philosophers to proceed everywhere from certain principles and to systematize all human knowledge, hermeneutics became a province of philosophy. Following the example of Aristotle . . . Enlightenment philosophers viewed hermeneutics and its problems as belonging to the domain of logic (Mueller-Vollmer, 1988, p. 3).

In the nineteenth and twentieth centuries, under the various influences of Romanticism, secularism, materialism, vitalism and phenomenology, hermeneutic studies became oriented towards psychological, historical and subjective aspects of interpretation. Although treatment of hermeneutics differs from author to author, it can be distinguished from semantics in being

- oriented more towards the holistic meaning of texts, rather than the individual meaning of smaller linguistic units such as sentences or words;
- focussed on historical and humanist explanations of interpretation rather than scientific and objective, truth-functional ones;
- more closely connected with traditional approaches to language—rhetoric, grammar, biblical exegesis, and language genealogy—than semantics (Leech, 1981; Mueller-Vollmer, 1988);
- directed towards the internal rather than external "side of our use of signs"—towards how signs are *understood*, rather than, conversely, how concepts can be *signified* (Gadamer, 2004);
- interested in disruptive semantic features of meaning—ambiguity, paradox and contradiction are not features to be "explained away", but rather are intrinsic characteristics of an account of meaning.

Twentieth-century philosophers working in the hermeneutic tradition have also pointed to a necessary structural relationship between holistic understanding and atomistic interpretation, depicted by the "hermeneutic circle" (Heidegger, 1962; Gadamer, 1975). It describes a virtuous rather than vicious circular pattern of learning in relation to a text, discourse or tradition—as individual parts are interpreted, so the understanding of the whole becomes clearer; and as the text as a whole is better understood, so new parts are better able to be interpreted. This broad structure describes in the large the kind of complementarity described earlier between two approaches to aligning ontologies: ontology matching—translating atomic concepts found within them—and assessing commensurability—comparing holistically the conceptual schemes underlying them. Similarly, where atomic interpretation works from the explicit features of the ontologies themselves, developing a holistic understanding also engages the implicit assumptions and commitments held by those who design and use them.

Although typically directed towards historical, literary or philosophical texts, then, hermeneutics makes several distinctions and claims which can be no less applied to the interpretation of ontologies and other information systems—as texts of a different sort. Whereas ambiguity in poetical texts is often intentional, it is an unhelpful side-effect of tacit assumptions in the case of ontologies—and a "broad-brush" hermeneutic orientation, which seek to examine texts against the background of historical and contextual conditions, can be useful in making such assumptions explicit.

2.1.4 Pragmatic Semantics

Linguistic pragmatics considers meaning a function of how words and phrases are used, famously coined in the Wittgensteinian expression "the meaning of a word is its use in the language" (Wittgenstein, 1963). According to this view, language, as well as being a repository of lexical items arranged according to various syntactic rules, primarily functions as a tool in the hands of linguistically capable agents. Utterances can be understood as acts, and are best analysed in terms of their effects. The meaning of words cannot be abstracted from their embeddedness in utterances, in the broader situational context in which those utterances are made, and in the practical effects they produce. Assertoric statements—of the kind analysed by formal semantics, whose semantic import could be judged by the truth-value of their propositional contents—are an unremarkable region in the broader landscape of linguistic utterances, which can be analysable against several other functional vectors (Austin, 1998). Unlike formal semantics, pragmatics focusses on a broader class of linguistic phenomena; unlike hermeneutics, this focus is less directed towards subjective interpretation, and more towards the social and intersubjective aspects of language use: speech acts, rules, functions, effects, games, commitments, and so on.

In 1950s, Austin (1998), Wittgenstein (1963), Quine (1980) and Sellars and Brandom (1997) collectively mounted a series of what can best be described as pragmatically inflected critiques against the naïve empiricism embedded within a logical positivist view of meaning, a view which can still be traced in the formal semantics tradition. Through a subsequent generation of philosophers, linguists and cognitive scientists, these critiques presented a range of new perspectives for understanding how semantic concepts are organised and used within a broader landscape of social practice.

In his landmark text *How to do Things with Words*, Austin (1998) discusses sentences whose functional role in discourse is distinct from that of assertional statements—that is, sentences which are not directly decomposable into propositional form. Austin directs attention particularly towards "performatives"—utterances which *do* things. Unlike descriptive statements, which can be analysed in terms of truth-content, such performative sentences have to be assessed against different criteria: whether they are successful in their execution, or in Austin's vocabulary, "felicitous" (Austin, 1998). He eventually introduces a trichotomous schema to characterise how a sentence functions:

1. As a *locutionary* act—"uttering a certain sentence with a certain sense and reference".
2. As a *illocutionary* act—"informing, ordering, undertaking, &c., i.e. utterances which have a certain (conventional) force".
3. As a *perlocutionary* act—"what we bring about or achieve *by* saying something, such convincing, persuading, deterring ...".

Searle (1969) offers an extended and systematic account of various kinds of such speech acts, as well as various means for understanding their function and effects in discourse.

Wittgenstein's account represents a yet more radical departure from a view which sees statement-making as the canonical and primary function of language—a view which was moreover emphatically outlined in his own earlier work (Wittgenstein, 1921). Understanding language meaning, again, means understanding how it is used *in practice*. He introduces the idea of language "games", to direct attention to the role utterances play as pseudo-"moves". Such games need not have winners, losers, or even outcomes—what is distinctive about any linguistic situation is that it conforms to rules understood—at least partially—by its interlocutors. Despite its presentation in an elliptical and short text, Wittgenstein's later work has been immensely influential. As well as motivating Rosch's studies of prototypes and family resemblances (Rosch, 1975; Lakoff, 1987), his work has also been influential in a range of intersecting disciplines—Toulmin's analysis of rhetoric and argumentation; Geertz' phenomenological anthropology, with an attentiveness to "thick" description and language games (Geertz, 2005); and different strains of French philosophy and social theory, stretching across Bourdieu (1990), Lyotard (1984) and Latour (2004).

Sellars' critique of empiricism broadly echoes those of Austin, Wittgenstein and Quine, but contains a more explicit and direct critique of empiricism (Sellars and Brandom, 1997). The "Myth of the Given", like the "Two Dogmas of Empiricism", forms part of the backdrop to the more recent pragmatist philosophy of Rorty, McDowell and Brandom. Sentential or propositional meaning is not ignored in all of these accounts. In *Making it Explicit*, for example, Brandom develops a monumental theoretical apparatus which connects a fine-grained analysis of assertions—the ground left behind by previous pragmatist accounts—with the social game of, as he puts it, "giving and asking for reasons" (Brandom, 1994). His brand of "analytic pragmatism" provides one of the foundations for the framework presented here, and is discussed in more detail in Chapter 4.

Several implications can be drawn from a general pragmatist orientation towards language for the commensurability framework developed here. Firstly, the main unit of pragmatic analysis is the sentential utterance rather than the word—focussing on the whole rather than the part. Secondly, a pragmatic treatment of meaning needs to be attentive not only towards the utterance itself, but also the situational context in which it is made—who is speaking, who is listening, what conventions are in operation, in what sequence utterances are made, what effects the utterance produces, and so on. Thirdly, definitional meanings can be understood not only as compositions of atomic parts—a series of denotations—but also only as codifications of convention—a bundle of connotations, associations and cultural practices. Fourthly, an utterance can be understood simultaneously at variegated, multi-dimensional levels of abstraction—as a direct assertion, as a move in a dialogical sequence, as a tactical move in a language game, or as an act which conforms to understood social norms and conventions.

At first glance, a pragmatist orientation might appear irrelevant for the interpretation of ontologies and other information schemes. After all, knowledge systems are developed in formal languages precisely to sidestep the kinds of ambiguities and "infelicitations" which plague natural language. While systems are *prima facie* expressions of definitions and assertions, however, they also serve other discursive roles—to persuade, convince, insinuate and facilitate further negotiation. Moreover they are used in quite specific *social* language games—as "tokens" in various kinds of political and economics games, for example. Interpreting knowledge systems pragmatically therefore means not only understanding their explicit commitments, but the roles they play in these extended language games. What are they developed and used for? What motivates their constructions—as very particular kinds of utterance? How are they positioned relative to other systems—what role do they play in the kinds of games played out between organisational, governmental, corporate and inter-departmental, for example? Pragmatism therefore provides a useful "step up" from viewing ontologies as representations of conceptual schemes to viewing them as *social* products—"speech acts", "utterances" and "moves" in very broadly conceived language games. It is also underlines the contextual relevance of commensurability assessments themselves—that interpretation and translation are also linguistic acts, performed for particular purposes and goals.

2.2 Cognitive Semantics

2.2.1 Theories of Categorisation

One way of considering knowledge systems are as formal mechanisms for classifying and categorising objects. Graphically, a typical ontology resembles a hierarchical taxonomy—though, technically, it is a directed acyclic graph, meaning that concepts can have more than a single "parent" as well as multiple "siblings" and "children"[1]. In such systems, concept application relies on objects meeting necessary and sufficient

[1] Ontologies also can support other sorts of conceptual relations, but the relationship of subsumption is axiomatised into the semantics of the OWL directly, as are several other relations.

conditions for class membership. This general model accords well with the broad tradition of category application stretching back to Aristotle. However, ontologies are intended to be machine-oriented representations of conceptualisations, with only an analogical relation to mental cognitive models. What, then, can be gleaned from contemporary theories of categorisation?

Since the 1960s, alternative models have been proposed for how mental concepts are organised and applied. Like ontologies, semantic networks, pioneered by Quillian (1967), model cognitive conceptual networks as directed graphs, with concepts connected by one-way associative links. Unlike ontologies these links do not imply any logical (or other) kind of relation between the concepts—only that a general association exists. Semantic networks were adapted for early knowledge representation systems, such as frame systems, which utilise the same graphic structure of conceptual nodes and links: "We can think of a *frame* as a network of nodes and relations" (Minsky, 1974). Minsky also explicitly notes the similarity between frame-systems and Kuhnian paradigms—what results from the construction of a frame-system as a viewpoint of a slice of the world (Minsky, 1974). By extension, semantic networks can be viewed as proto-paradigms in the Kuhnian sense, though it is not clear what the limits between one network and another might be—this analogy should not, then, be over-strained.

A feature of semantic networks is the lack of underlying logical formalism. While Minskian frame-systems and other analogues in the 1970s were "updated" with formal semantic layers, notably through the development of Description Logics in the 1980s, according to Minsky the lack of formal apparatus is a "feature" rather than a "bug"—imposition of checks on consistency, for example, impose an unrealistic constraint on attempts to represent human kinds of knowledge, precisely because humans are rarely consistent in their use of concepts (Minsky, 1974). At best they are required to be consistent across a localised portion of their cognitive semantic network, relevant to a given problem at hand, and the associated concepts and reasoning required to handle it. Similarly the authors of semantic network models note the difficulty in assuming neatly structured graphs model mental conceptual organisation: "Dictionary definitions are not very orderly and we doubt that human memory, which is far richer, is even as orderly as a dictionary" (Collins and Quillian, 1969). Semantic networks represent an early—and enduring—model of cognition which continues to be influential in updated models such as neural networks and parallel distributed processing (Rogers and McClelland, 2004). Such networks also exhibit two features of relevance to the theory adopted here: firstly, the emphasis on structural, *connectionist* models of cognition—that concepts are not merely accumulated quantitatively as entries in a cognitive dictionary, but are also inter-connected, so that the addition of new concepts makes a qualitative difference in how existing concepts are applied; and secondly, the implied *coherence* of networks, which suggests concepts are not merely arranged haphazardly but form coherent and explanatory schemes or structures.

In the mid-1970s, prototype theory, another cognitive model, was proposed for describing concept use. Building on Wittgenstein's development of "language games" (Wittgenstein, 1963), Rosch (1975) demonstrated through a series of empirical experiments that the process of classifying objects under conceptual labels was generally *not* undertaken by looking for necessary and sufficient conditions for concept-hood. Rather, concepts are applied based on similarities between a perceived object and a conceptual "prototype"—a typical or exemplary instance of a concept. Possession of necessary and sufficient attributes is a weaker indicator for object inclusion within a category than the proximation of the values of particularly salient attributes—markers of family resemblance—to those of the ideal category member. For example, a candidate dog might classified so by virtue of the proximity of key perceptual attributes to those of an ideal "dog" in the mind of the perceiver—fur, number of legs, size, shape of head, and so on. Applying categories on the basis of family resemblances rather than criterial attributes suggests that, at least in everyday circumstances, concept application is a vague and error-prone affair, guided by fuzzy heuristics rather than strict adherence to definitional conditions. Also, by implication, concept application is part of *learning*—repeated use of concepts results in prototypes which are more consistent with those used by other concept users. This would suggest a strong normative and consensual dimension to concept use. Finally, Rosch (1975) postulated that there exists "basic level semantic categories", containing concepts most proximate to human experience and cognition. Superordinate categories have less contrastive features; subordinate categories have less common features—hence basic categories tend to be those with more clearly identifiable prototypical instances, and so tend to be privileged both in concept learning and use.

While both semantic network and prototype models provide evocative descriptive theories that seem to capture more intuitive features of categorisation, they provide relatively little *causal* explanation of how particular clusters of concepts come to be organised cognitively. Several new theories were developed in the 1980s with a stronger explanatory emphasis (Komatsu, 1992). Medin and Schaffer, for example, propose an exemplar-based "context" theory rival to prototype theory, which eschews the inherent naturalism of "basic level" categorial identification for a more active role of cognition in devising "strategies and hypotheses" when retrieving memorised category exemplar candidates (Medin and Schaffer, 1978). Concept use, then, involves agents not merely navigating a conceptual hierarchy or observing perceptual family resemblances when apply concepts; they are also actively formulating *theories* derived from the present context, and drawing on associative connections between concept candidates and other associated concepts. In this model, concept use involves scientific theorising; in later variants, the model becomes "theory theory" (Medin, 1989). As one proponent puts it:

> In particular, children develop abstract, coherent systems of entities and rules, particularly causal entities and rules. That is, they develop theories.

> These theories enable children to make predictions about new evidence, to interpret evidence, and to explain evidence. Children actively experiment with and explore the world, testing the predictions of the theory and gathering relevant evidence. Some counter-evidence to the theory is simply reinterpreted in terms of the theory. Eventually, however, when many predictions of the theory are falsified, the child begins to seek alternative theories. If the alternative does a better job of predicting and explaining the evidence it replaces the existing theory (Gopnik, 2003, p. 240).

Empirical research on cognitive development in children (Gopnik, 2003) and cross-cultural comparisons of conceptual organisation and preference (Atran et al., 1999; Ross and Medin, 2005; Medin et al., 2006) has shown strong support for "theory theory" accounts. Quine's view of science as "self-conscious common sense" provides a further form of philosophical endorsement to this view.

For the purposes of this study, a strength of the "theory theory" account is its orientation towards conceptual holism and schematism—concepts do not merely relate to objects in the world, according to this view (although assuredly they do this too); they also stand within a dynamic, explanatory apparatus, with other concepts, relations and rules. Moreover theories are used by agents not to explain phenomena to themselves, but also to others; concept use has then both a role in one's own sense-making of the world, and also in how one describes, explains, justifies and communicates with others. In short, concepts are understood as standing not only in relation to objects in the world, as a correspondence theory would have it; they stand in relation to one another, to form at least locally coherent mental explanations; and they also bind together participating users into communities and cultures. The account presented here similarly draws upon supplemental *coherentist* and *consensual* notions of truth to explain commensurability.

2.2.2 Semantics and the Embodied Mind

Several other influential cognitive models have also been proposed. Drawing together several diverse theoretical strains—generative semantics, phenomenology, and Rosch's earlier work—Lakoff and Johnson (1980) suggest that analogical and associative processes of *metaphorisation* are central to describing concept use and organisation. Eschewing logically-derived models popular in the 1960s and 1970s, Johnson and Lakoff contend that conceptualisation is at least strongly influenced, if not causally determined, by the cognitive agent's physical and cultural orientation. Rational minds are therefore subject to a kind of phenomenological embeddedness within a physical and cultural world—even the most abstract conceptualisations can be shown to "borrow", in the form of metaphorical structures, from the perceptual and intersubjective worlds we inhabit. To take one of the case study examples presented later, "upper-level" or "foundational" ontologies are so-called because "upper" refers to the head, the sky or the heavens—the phenomenological locus of conceptual abstraction—while "foundational", though physically inverted, refers to structural support, substance—again, the phenomenological, and etymological, locus of conceptual "depth". Johnson and Lakoff seek to explain not only individual concept use by this kind of metaphorical reduction, but also larger conceptual clusters, which when transposed from the immediate and physical to some more abstract field, provide a means of understanding that field economically and coherently.

Lakoff and others develop tantalising glimpses of a metaphorical account of cognition, grounded in the "embodied mind", in several subsequent works, notably Lakoff (1987); Varela et al. (1992); Dennett (1991). In part his critique—as with Rosch—is directed towards a mechanistic or computational theory of mind, which views cognition as a series of abstract operations which could be conceivably replicated on any suitable hardware—biological or otherwise. Implied in this view is a form of Cartesian mind-body dualism; a *false* dualism according to Lakoff (1987) and Dennett (1991). What can be extracted from these kinds of critique is a cautionary and corrective view that sees cognition as irretrievably bound to a physically and socially embedded agent, intent on making sense of new experience by drawing upon an existing reserve of culturally shared, coherent conceptual constructs. Above all, both conceptual and physical experiences here are firmly oriented within a series of "cultural presuppositions", as Lakoff and Johnson suggest:

> In other words, what we call "direct physical experience" is never merely a matter of having a body of a certain sort; rather, *every* experience takes place within a vast background of cultural presuppositions. It can be misleading, therefore, to speak of direct physical experience as though there were some core of immediate experience which we then "interpret" in terms of our conceptual systems. Cultural assumptions, values, and attitudes are not a conceptual overlay which we may or may not place upon experience as we choose. It would be more correct to say that all experience is cultural through and through, that we experience our "world" in such a way that our culture is already present in the very experience itself (Lakoff and Johnson, 1980, p. 57).

Lakoff and Johnson's metaphorical model, while clearly capturing some part of the way concepts are transferred over domain boundaries, nonetheless suffers from a problem of theoretical indeterminacy—it fails to account for why *some* metaphors are used and not others. Moreover, it arguably does not give sufficient agency to concept users—under their theorisation of cognition, it is not clear how concept users are any more than passive adopters of a shared collective cultural heritage. The *creative* use of metaphor, much less the range of other, non-metaphorical linguistic actions, such as various forms of deductive, inductive or abductive reasoning, are not explicitly treated in their account.

2.2.3 Geometries of Meaning—the Re-emergence of Conceptual Structure

In part to gather up both traditional and more progressive theories of categorisation, several more recent models have been proposed. These are at once highly systematic, and tolerant of the problems of vagueness and fuzziness which had plagued older logistic approaches. Gardenfors (2000), for instance, proposes a sophisticated geometric model of cognition, which blends together more conventional cognitive elements—concepts, properties, relations, reasoning—with some of the suggestive elements proposed by Lakoff and others. Rogers and McClelland (2004) put forward what they term a "parallel distributed processing" account of semantic cognition, which builds upon the descriptive and explanatory strengths of "prototype" and "theory" theories, while attempting to remedy their defects. Goldstone and Rogosky (2002) propose an algorithmic approach to translation across what they call a "conceptual web", presupposing both holistic conceptual schemes and a quantifiable notion of semantic distance separating concepts within and across schemes. While these recent accounts are themselves quite different in approach and findings, they share a greater willingness to use computational and geometrically inspired models to explore feasible modes of cognitive activity. These kinds of studies are evidence of a kind of re-systematisation taking place in the cognitive sciences, as (qualified) structural models once more come to the fore. Unsurprisingly, such models are also well suited to describing *representations* of conceptual systems in ontologies and schemas. At the same time, the model presented by Gardenfors (2000) in particular can be reconciled with the kinds of experiential phenomenology and cultural embeddedness which feature in the work of Lakoff and Johnson (1980). Chapter 4 employs Gardenfors' model of cognition directly in relation to the question of commensurability, connecting it to the pragmatist-infused account of language offered by Brandom, and the more general social theory of Habermas, as the basis for generating comparative views of conceptual schemes ("conceptual spaces" in Garderfors' vocabulary) across different cognitive, linguistic and cultural tiers.

2.3 Social Semantics

The following section aims to sample some of the prevailing paradigms of sociological theory and research in relation to semantics, and specifically in its intersection with technological kinds of meaning formation.

2.3.1 Sociology of Knowledge

The semantic models put forward so far consider the creation and dissemination of meaning to be first and foremost a concern of individual rational agents, in which the influence of culture is a secondary and frequently distorting feature. The sociology of knowledge, following Marx and Nietzsche—both suspicious of knowledge's purported independence from its conditions of production—attempts to explain how different epistemic "perspectives" emerge (Mannheim, 1998). A more modern rendering describes sociology of knowledge as an inquiry into how knowledge is constituted or constructed within a social or cultural frame of reference (Hacking, 1999). That is, knowledge is taken within such inquiry as not only trivially social—in the sense that it typically involves more than a single actor—but also, and fundamentally, as a product of social forces and relations. While epistemological inquiry has always sought to understand the role of external influences—usually negative ones—on the development of knowledge—even Socrates' attack on the sophists can be read in this vein—nevertheless there is a specific trajectory that can be traced across twentieth century thought. This trajectory leads from Mannheim's *Ideology and Utopia* in the 1930s (Mannheim, 1998), through to a revival in Kuhn, Foucault, Bloor and Latour in the 1970s (Kuhn, 1970; Foucault, 1970; Bloor, 1991; Latour, 1993), up to a flurry of present-day sociological interest in the natural and social sciences—most notably in the field of *Science and Technology Studies* (Hacking, 1999; Keller, 2005).

Sociology of knowledge proponents are frequently accused of "relativising" knowledge, making it little more than a circumstantial side-effect of social or cultural context (Davidson, 2006; Pinker, 1995). As several authors note (Bloor, 1991; Hacking, 1999, 2002), however, discussing social constructions of knowledge need not imply adoption of a relativising stance. Rather it can involve understanding why particular problems of knowledge—and solutions—might present themselves at various times. Moreover such an approach can be open to a two-way, dialectic relationship between knowledge and society—arguing that society (however broadly construed) is equally formed through the production of ideas, theories, facts and statements, as much as knowledge artefacts themselves are formed by societal influences. Treating knowledge as a social construct need not therefore be a one-way descent into epistemic relativism, in which all "facts" can be merely be explained away as by-products of cultural forces, power relations or other social entities.

Applied to contemporary knowledge representation systems, as a general rubric, sociology of knowledge has much to recommend it. It opens a way to investigate not only *which* perspectives emerge in relation to some domain of knowledge, but also *how* those perspectives are coordinated with respect to each other—how, for instance, one perspective within a given domain can cause others to emerge as well, in opposition, or sometimes perhaps, in an uneasy alliance. It also provides a convenient lexicon to move from technical discussions of ontologies—as knowledge artefacts—through to a general cultural field of perspectives, orientations, world-views and stand-points. Moreover it suggests that it is possible, when looking at an object like a formal knowledge system through a sociological historical lens, to see it less in either strictly idealist terms (as intellectual history pure and simple, as the production of useful theorems and theses by enlightened minds), or in strictly materialist terms (as the net effect of particular economic, political, governmental or military forces), but rather as something like the dialectical and probabilistic outgrowth of both idealistic and materialistic forces. As the case studies demonstrate, while ascribing direct causal influence on the production of knowledge systems is inveterately difficult, it is still possible to paint a plausible—and epistemologically defensible—portrait of the complex interplay of these forces.

Swidler and Arditi (1994) note that considerable attention has been devoted towards a "sociology of informal knowledge". As the survey of science and technology studies below shows, there have been many studies of various kinds of "formal knowledge" too. However, the term "sociology of formal knowledge" is an apt epithet for the kind of approach adopted here—the study of the perspectival standpoints which underpin formal knowledge systems, where "formal knowledge system" specifically means the encoding of some knowledge (a series of concepts, relations and individual objects) in a formal language. One of the claims of the study is that studying knowledge systems as social or cultural artefacts is not only a matter of interest to a sociologist of knowledge, but also provides practical guidance to a systems analyst faced with "day-to-day" problems of conceptual translation across perspectival divides—indeed the claim suggests, perhaps, that these two disciplinary roles increasingly converge in "networked societies" (Castells, 1996) where the technological and the anthropological are inseparably intertwined.

As a fitting example of one such "intertwining" is the term "ontology" itself. Although the term is introduced in its computer science appropriation in Chapter 1, in its modernised philosophical sense "ontology" can be understood as the historical and cultural ground against which conceptualisations are developed. This view of ontology, freeing it from its metaphysical roots as the study of "what is", is succinctly encapsulated by Hacking:

> Generally speaking, Foucault's archaeologies and genealogies were intended to be, among other things, histories of the present . . . At its boldest, historical ontology would show how to understand, act out, and resolve present problems, even when in so doing it generated new ones. At its more modest it is conceptual analysis, analyzing *our* concepts, but not in the timeless way for which I was educated as an undergraduate, in the finest tradition of philosophical analysis. That is because the concepts have their being in historical sites. The logical relations among them were formed in time, and they cannot be perceived correctly unless their temporal dimensions are kept in view (Hacking, 2002, pp. 24–5).

In Chapter 4, some of the "sociologists of knowledge" introduced here—in particular, Kuhn, Foucault and Hacking—are discussed in more detail. For now, this introduction is intended to demonstrate how the tradition of the sociology of knowledge strongly informs the approach adopted in this study. It also suggests that an analysis of commensurability aims, ideally, to shed light on the historical and cultural conditions—to the degree that these can be ascertained—of ontology construction and design. What at a first glance can pose itself as a largely technical exercise, of mapping, matching and aligning ontological concepts, can at its further degree present itself instead as a complex task of translation across cultural conceptual schemes, or in Hacking's phrase, "historical ontologies"; the aim of the framework is, in part, to help analyse concepts and their schemes against a broader historical and cultural backdrop. Knowledge systems, no less than any other cultural artefact, "cannot be perceived correctly unless their temporal dimensions are kept in view" (Hacking, 2002).

Critical Theory as a Sociology of Knowledge

The historical dimension to ontological standpoints is analysed further by the critical theory tradition. Developed out of the work of Marx, Weber and Lucáks, critical theory dispenses with what it sees are idealistic aspects of sociology of knowledge—or rather, re-orients these upon the materialist conditions of knowledge production (Popper and Adorno, 1976). Different perspectival orientations, in more extreme variants of this view, are the apparent epiphenomena which develop out of the structural character of the economy at given moments in history (Horkheimer and Adorno, 2002). While differences of opinion might always be free to circulate in any society, fundamentally incommensurable world-views, irreconciliable through rational discourse, are the product of the alienating forces of modern capitalism, which rigidifies human relations in terms of class structure.

Habermas sought to free analyses of knowledge and communication from the more deterministic aspects of critical theory, while retaining its materialist foundations. His theory of communicative action points to several complex overlapping dimensions in post-Enlightenment society. For Habermas, the fundamental rift between objective system and subjective lifeworld can be attenuated through the intersubjective sphere of communication and discourse (Habermas, 1987). Within this orbit, different knowledge formations are free to circulate, with the potential to reconfigure structural inadequacies in the growing systematisation of individual lifeworlds enacted by capitalism.

Luhmann provides a related frame of reference via systems theory (Arnoldi, 2001; Baecker, 2001). Not at all assimilable to critical theory, Luhmannian systems nevertheless provide some elaboration on the objectivist, "system" side of the critical theoretical coin. For Luhmann, systems are "autopoetic"—they engender their own frames of meaning around a critical "distinction". For economic systems, for example, the motivating distinction is the presence or absence of money. The distinction then structures the cluster of concepts which inform how those in the system operate. Luhmann's views have some analogies with the model of culture put forward in Chapter 5; however, for reasons of parsimony, the theoretical cues from Habermas' admittedly less developed account of the complex overlays of systems in contemporary society, which provide a plausible generative and sufficiently abstract account of the divisions which fissure through contemporary knowledge systems, are instead adopted here. I return to Habermas in more detail in Chapter 4, where his theoretical apparatus is woven in among more fine-grained analyses of language and cognition.

Globalisation and Technologies of Knowledge

Related forms of social theory and research have investigated the rise of information technology and the correlative phenomenon of globalisation. Castells (1996), for instance, documents exhaustively the emergence of the "network society", in which traditional forms of labour, organisation, urban planning, travel, markets, culture, communication, and finally, even human subjectivity, are transformed by the "network"—a metonymic substitute for various kinds of physical and information networks that parallel the growth of globalisation and late or "hyper" capitalism at the turn of the millennium. According to Castells, the ontological "horizon" of modern times is *qualitatively* different partly due to *quantitatively* expansive affordances offered by network effects or externalities. This results not in a simple homogenising of cultural differences; rather, echoing the Frankfurt School and Habermas, the "global network of instrumental exchanges"

> follows a fundamental split between abstract, universal instrumentalism, and historically rooted, particularistic identities. Our societies are increasingly structured around a bipolar opposition between the Net and the Self (Castells, 1996, p. 3).

Just as, for Habermas, radical ontological incommensurability arises between the system and the lifeworld, so Castells sees a similar structural schism between "the Net and the Self", and its various conceptual analogues—culture and nature, society and community, function and meaning. The rise of the network society therefore produces incommensurability as an "unintended consequence" precisely because of its globalising, standardising and homogenising character; it creates localised resistances in the fissures or lacunae of its network. However, for Castells as for Habermas, these differences can always be negotiated by the proselytising force of communication itself, with ambiguous effects:

> Because of the convergence of historical evolution and technological change we have entered a purely cultural pattern of social interaction and social organization. This is why information is the key ingredient of our social organization and why flows of messages and images between networks constitute the basic thread of our social structure (Castells, 1996, p. 508).

2.3.2 Studies on Technology and Science

Many of the pre-occupations of the "sociology of knowledge" have been inherited by more recently emergent disciplines, such as Science and Technology Studies (STS). Largely inaugurated through Latour and Woolgar's seminal anthropological study of a scientific laboratory (Latour and Woolgar, 1986)—though equally influenced by earlier "structural" histories of science and technology—STS work for the most part looks to examine the sites and practices of science and technology. A common feature of STS research generally, and of research inspired by the closely aligned Actor-Network Theory (ANT) in particular, is the desire to show how clear-cut conceptual boundaries—even those apparently fundamental, between subject and object, nature and culture, active and passive agents—become blurred in scientific practice (Latour, 1993; Law, 1992, 2004). Not a "theory" in the usual sense, owing more to Geertz's "thick" methodological approach to ethnography than explanatory sociological models (Latour, 2004), ANT has nonetheless provided a broad rubric and vocabulary for researchers attempting to analyse how different knowledge formations are constructed socially, or as Law puts it, "scientific knowledge is shaped by the social" (Law, 2004). And as information technology has began to play an important role in many scientific disciplines, many STS studies have increasingly paid attention to the social construction of computational systems of classification.

Bowker and Star (1999), for instance, examine how active political and ethical choices become invisible once encoded within classificatory schemes in a variety of bureaucratic contexts: medical, health and governmental demography. Adopting the term "information infrastructures" to describe how such schemes facilitate organisational practices just as physical infrastructure might do, their analysis develops its own set of distinguishing—and inter-related—typological features. Classification systems can be

- *Formal/scientific* or *informal/folk*—*formal systems* are used in "information science, biology and statistics, among other places", while *informal systems* are "folk, vernacular and 'ethno-classifications' ".
- *Pragmatic* or *idealistic*—*pragmatic* systems tend to be oriented towards a limited set of contemporary goals; *idealistic* systems are future-oriented, trying to anticipate future uses.
- *Backwards-compatible* or *future-oriented* (related to the previous distinction)—*backwards-compatible* systems endeavour to harmonise categories with pre-existing schemes and data-sets; *future-oriented* systems are developed from relatively new principles or methods.
- *Practical* or *theoretical*—*practical* systems tend to evolve to meet the needs of new users and applications, and may lose original motivating principles; *theoretical* systems tend to retain such principles as endemic to their operation.

- *Precise* or *prototypical*—*prototypical* taxonomies provide "good enough" descriptive labels, rather than rigorous necessary and sufficient conditions, recalling Rosch's distinction outlined above (Rosch, 1975).
- *Parsimonious* or *comprehensive*—*parsimonious* systems capture only a limited number of fields; *comprehensive* systems aim to gather as much information as possible.
- *Univocal* or *multivocal*—*univocal* systems tend to reflect a singular, authoritative perspective; *multi-vocal* systems tend instead to reflect multiple interests.
- *Standardised* or *eccentric*—*standardised* systems reflect a mainstream view of field or domain; *eccentric* systems adopt idiosyncratic, unique or otherwise alternative organisations of concepts.
- *Loosely* or *tightly* regulated—*loosely* regulated classifications systems develop *ad hoc*—through trial and error, and incremental revision; *tightly* regulated systems tend to have formal review processes and versioning systems[2].

As the authors make clear, many of these distinctions are of degree rather than kind—systems may be more or less formal in the above sense, for example. These distinctions motivate several of the second-order dimensions introduced in the framework in Chapter 5; there they are applied as a means of classifying classification systems themselves.

In a series of further case studies, Bowker and Star (1999) also demonstrate the complexity of factors that motivate particular categorial distinctions behind classification systems. They highlight the inherent fuzziness and historical residues that accrue to systems over time; demonstrating how, for instance, political and ethical values become embedded long past their historical valency. Such critical impulses can also be found in a number of more recent studies—Smart et al. (2008), for instance, look at how racial and ethnic categories become homogenised within scientific classification systems. Other studies have also described the complications arising from overlapping or conflicting *methodological* approaches to classification. Sommerlund (2006) demonstrates how conflicting genotypical and phenotypical methodological approaches impact on research practices in molecular biology. In another study, Almklov (2008) has shown how formal classification systems are supplemented in practice by informal heuristics, as "singular situations" need to be interpreted against potentially incommensurable "standardised" conceptualisations and data sets. The negotiated process of meaning-making involved in devising classification systems between diverse disciplinary experts has also recently received attention; for example, a study by Hine (2006) of "geneticists and computer engineers" devising a mouse DNA database.

[2]Adapted from Bowker and Star (1999)

The desire to renovate classification systems—either through development of new systems, or refinements to existing ones—can, then, be motivated by numerous extrinsic social factors. As these various studies show, *individual* classifications systems can be shown to exhibit conflicting tensions and practical trade-offs in their design, construction and application. Seeking to understand the commensurability of *multiple* systems amplifies the potential noise generated by these tensions; tracing them in turn relies upon examining each system against a matrix of inter-related dimensions—including both the kinds of distinctions outlined above, and also a further series of contextually-determined and more or less implied distinguishing elements: political and ethical beliefs, disciplinary methodologies, theoretical-practical overlays, and vocational orientations. The resulting profiles can in turn be used for comparing and contrasting the systems concerned—or, in the language adopted here, for assessing their commensurability.

2.3.3 IT Standardisation

Central to the rise of globalisation has been the phenomenal growth of standardisation, a process of negotiated agreement across many social layers—from common legal frameworks, economic agreements, political affiliations and linguistic consensus, through to a myriad of ratified protocols, specifications and standards for mechanical, electrical, engineering, communications and information technology instruments. Considerable research has been directed towards standardisation in the information technology sector specifically, much of it published through a journal dedicated to the field, the *Journal of IT Standards and Standardization Research*. Unlike the preceding science studies, which for the most part adopt an anthropological orientation towards the production of technical artefacts, this research views standardisation as a predominantly economic phenomenon—though with important political, legal and cultural bearings. Where an anthropological view is useful in bringing out the internal perspectival character of knowledge systems, describing *how* and *why* these systems became widely used and adopted often requires a broader scope—looking at the complex interplay between individual actors, corporations, governments and multi-national consortia, well beyond the laboratory or workplace setting—and commensurately, employing different research methods, examining the motivations and processes of standardisation primarily through historical and documentary evidence, rather than first-hand observation. From the point of view of developing a set of descriptive criteria or dimensions for describing the cultures responsible for knowledge systems, studies of standardisation provide a valuable supplementary source. The sorts of distinctions developed here have, moreover, particular resonance in one of the case studies, the standardisation of document schemas presented in Chapter 8.

Standards exists for a wide range of technical formats, protocols, processes and applications, and studies of IT standardisation have been accordingly eclectic—covering style languages (Germonprez et al., 2006), E-Catalog standards (Schmitz and Leukel, 2005), e-commerce (Choi and Whinston, 2000), mobile platforms (Tarnacha and Maitland, 2008), operating systems (Hurd and Isaak, 2005; Isaak, 2006; Shen, 2005), project management (Crawford and Pollack, 2008) and software engineering processes (Fuller and Vertinsky, 2006). The term “standard” itself is notoriously difficult to define—Kurihara (2008) points to its French etymological origins as a military “rallying point”; it has since been co-opted into economic parlance as being “required for communication between the labeled product and its user in order to win the fullest confidence of the market”. Blum (2005) suggests standards can be divided into “public” and “industrial” types; “public” standards can be further distinguished between national and sector-specific, while “industrial” standards can be either company or consortia-based. Blum also suggests further criteria for considering standardisation processes: the “speed of the process”; “outcomes”, in terms of the competitive conditions of market; “legal status”; and the “nature of the economic goods created”—whether they be closed or open, public or private (Blum, 2005). These criteria are picked up further on in the presentation of the framework.

Several motivations have been identified for the development and use of standards. Most commonly, authors point to one or more economic rationales. For example, Krechmer (2006) identifies three economic beneficiaries of standardisation: governments and market regulators looking to promote competition; lowered production and distribution costs for standards implementers; and user or consumer benefits brought about by a standard’s adoption. Hurd and Isaak (2005) adds a fourth group: individuals, usually professionals, benefitting by certain kinds of standards certification and professionalisation. In addition, they note that standardisation benefits companies at all stages of a product’s lifecycle: by accelerating the initial rate of technology adoption and product diffusion; by expanding the functionality of a product as it matures; and by extending the lifetime of a product as it becomes obsolete or redundant in the face of new, emergent products (Hurd and Isaak, 2005). The personal motivation which accrues to individuals through their involvement in standards development and certification processes is further noted by Isaak (2006) and Crawford and Pollack (2008). Similarly, standardised quality processes accompanied by internationally-recognised certification, can help differentiate a company in a crowded market-place—as Fuller and Vertinsky (2006) observe, certification can, in some cases, even be a good market indicator of “improved future revenues”. Moreover numerous authors have emphasised the direct and indirect benefits of “network externalities” which technology process, product and platform standardisation brings to users (Katz and Shapiro, 1985; Zhao, 2004; Park, 2004; Tarnacha and Maitland, 2008; Parthasarathy and Srinivasan, 2008).

The by-products of standardisation are not, however, always beneficial. Van Wegberg (2004) discusses the trade-offs between “speed and compatibility” in the development of standards, focussing particularly on the problematics of competing standardisation efforts instigated by rival industrial consortia—a thematic which is revisited in the document formats study in Chapter 8. The fractious effects of multiple standards are further studied by Tarnacha and Maitland (2008) and Schmitz and Leukel (2005)—though authors are divided as to whether such problems arise from excessive competition, over-regulation, or are in fact intrinsic side effects of market dynamics. The costs of standards compliance and certification processes can also produce negative unintended consequences, operating as market barriers to entry, and limiting rather than fostering market competition (Tarnacha and Maitland, 2008). Furthermore, consequences can be culturally discriminatory: as one study has shown, on a national level standardisation can lead to adverse effects for "indigenous technology developments" (Shen, 2005), as the dispersion of proprietary, closed standards, in particular, can inhibit local training, innovation and industrial development. Again echoing the document format controversy discussed in Chapter 8, Shen's analysis of the rivalry between Microsoft and Linux operating systems in China points to potential negative normative and even imperialist implications of purely market-driven standardisation, if unattended by adroit legal and political policy. Even relatively benign professional bodies, with no direct economic or political mandate, can, in developing standards, implicitly promote national or regional agendas into global ones—at the potential risk of marginalising those with less resources or authority (Crawford and Pollack, 2008; Parthasarathy and Srinivasan, 2008). Moreover, corporations have become experts at "gaming" the standards process, both by overt political and economic influence, and by covert "patent ambush", in which "submarine" patents are submitted as part of otherwise "open" or "fair and reasonable" technological provisions to standards, only to resurface at the corporate donor's leisure—if new products or technologies inadvertently infringe upon the patents (Hemphill, 2005). Market dynamics also often foster so-called "standards wars", in which companies form competing consortia promoting rival standards—a process which fragments the market and dilutes the network externalities of standards, at least until a dominant candidate emerges (Parthasarathy and Srinivasan, 2008).

Consequently, while many studies note the generally beneficial nature of standardisation, such processes—and the technical artefacts they produce—can be seen as part of a social negotiation between different kinds of co-operative and competitive agents, engaged in a series of complex trade-offs. In the case of ontologies and schemas, standardisation is often their very *raison d'être*—broad diffusion and adoption being key elements of their promise to deliver interoperability. Understanding commensurability of ontologies, then, can often involve understanding the methods and means by which their authors endeavour to make them standards. Of the studies surveyed, only Schmitz and Leukel (2005) offer something of a typology of distinguishing features of standards; they propose the following for the purpose of choosing e-catalog standards:

- General:
  - What is the market penetration of the standard—current and future?

    - What is the quality of the standard?

- Specific:
    - Standard Organisation—How long will it remain effective? What level of power and international exposure does it have? What is the level of user involvement?
    - Methodology—Is the underlying language of the standard highly formalised? Machine-readable? Sufficiently expressive?
    - Standard Content—Is the standard at right level? What objects are categorised? Is the coverage right and satisfying?

Some of these specific features are picked up and reworked as descriptive dimensions later in the framework presented in Chapter 5. More generally, this review of standardisation studies has extracted a number of dimensions which can be applied to knowledge systems, particularly to the areas of process and motivation of system design. These dimensions include:

- Open versus closed process;
- Levels of *de facto* and *de jure* standardisation;
- Size and levels of community activity around standards;
- Adoption rates, industry support, levels of satisfaction with standards;
- Differing motivations—economic, political, legal, social, technical.

2.3.4 Knowledge Management

Knowledge systems can also be studied through yet another disciplinary lens, that of knowledge management (KM). KM approaches tend to discuss ontologies less as kinds of classification systems or standards, and more as a kind of intangible organisational asset (Volkov and Garanina, 2008). This perspectival shift brings about yet further distinctions which can be used to compare and contrast ontologies. Moreover, the literature review now moves closer to dealing with ontologies as a subject proper—increasingly knowledge management has co-opted ontologies as an exemplary kind of knowledge representation, with numerous studies explicitly proposing or examining frameworks, processes and systems for handling ontologies in knowledge management journals (Bosser, 2005; Härtwig and Böhm, 2006; Lanzenberger et al., 2008; Lausen et al., 2005; Macris et al., 2008; Okafor and Osuagwu, 2007).

Much attention in knowledge management studies is devoted to describing the relationship between tacit and explicit knowledge in an organisational context. Nonaka and Takeuchi (1995) put forward a widely adopted model for describing this relationship, which follows a four-step process of "socialization" (tacit-to-tacit), "externalization" (tacit-to-explicit), "combination" (explicit-to-explicit) and "internalization" (explicit-to-tacit). Hafeez and Alghatas (2007) study how this model can be applied learning and knowledge management in a virtual community of practice devoted to Systems Dynamics. They also demonstrate how discourse analysis of online forums can be employed to demonstrate a process of knowledge transfer between participants—a method increasingly used to capture features of "virtual" communities generally. These communities are an increasingly prevalent cultural setting for knowledge dissemination, as Restler and Woolis (2007) show; similarly, discourse analysis is used in several of the case studies in this work. Other studies extend similar knowledge diffusion models to the whole organisation life-cycle (Mietlewski and Walkowiak, 2007), or examine the application of such models as specific interventions into organisations, in the form of an action research program aimed at improving knowledge elicitation processes (Garcia-Perez and Mitra, 2007). Al-Sayed and Ahmad (2003) also show how expert knowledge exchange and transfer is facilitated within organisations by "special languages"—limited and controlled vocabularies—which represent "key concepts within a group of diverse interests". As the authors point out, while use of such languages can serve to further the political aims of a specialised group within an organisation, the primary aim is one of parsimony "for reducing ambiguity and increasing precision" within a professional context (Al-Sayed and Ahmad, 2003). Such "languages for special purposes" (LSP's) can serve to reify a given set of lexical items into discourse, giving rise to particular conceptualisations within a knowledgeable community of practice. In turn, these are frequently codified into knowledge systems; understanding the practical generative conditions of such languages is one way, then, towards understanding and describing the assumptions behind these systems.

Several authors (Hughes and Jackson, 2004; Detlor et al., 2006; Loyola, 2007; Soley and Pandya, 2003) have sought to analyze the specific roles played by context and culture—two notoriously ill-defined concepts—in the formation, elicitation and management of knowledge. Acknowledging the resistance of the term "culture" to easy definition, much less quantification, Soley and Pandya (2003) suggest a working definition: culture is a "shared system of perceptions and values, or a group who share a certain system of perceptions and values", which would include "sub-groups, shared beliefs and basic assumptions deriving from a group". This working definition arguably ignores an important dimension of shared or collective *practice* which, following Bourdieu (1990), would seem constitutive of any culture. Nonetheless the authors point to important ways in which various cultural attributes—technical proficiency, economic wealth, as well as linguistic, educational and ethical characteristics—impact upon knowledge sharing, and suggest, anticipating some of the same points made in this study, that a certain degree of sensitivity and comprehension of culture has material consequences—although, in their case, these consequences are subject to the overall "game" of corporate competition.

Both Detlor et al. (2006) and Loyola (2007) seek to understand the role that a similarly vexed concept, *context*, plays in knowledge management. Detlor et al. (2006) provide a structural account of the relationship between a "knowledge management environment" and both organisational and personal information behavioural patterns, using a survey-driven approach to show that indeed a strong causal relationship exists. In their analysis, four survey items relating to "environment" (used interchangeably here with "context") reference terms like "culture", "organisation", "work practices, lessons learned and knowledgeable persons" and "information technology"—as well as "knowledge" and "information"—which suggests the notion of "context" here is synonymous with the modern organisational bureaucracy. Loyola (2007), on the other hand, surveys approaches which seek to formalise context as a more abstract "feature" of knowledge descriptions. Building on earlier work in this area by (Akman and Surav, 1996; Bouquet et al., 2003), Loyola (2007) argues these approaches strive to describe context either as part of a logical language, or as part of a data, programming or ontological model. Recognising that context is frequently tacit in knowledge representations—that it "characterises common language, shared meanings and recognition of individual knowledge domains"—Loyola examines attempts to make it explicit as a kind of knowledge representation itself. After a comparative review, he concludes an ontology developed by Strang et al. (2003) is best suited to describing context, and sees the explicitation of context as a itself a vital part of facilitating interoperability between conceptual, informational and social divides.

While no studies address the specific question posed here about the commensurability of multiple ontologies, the relationships sketched in this literature between knowledge assets, on the one hand, and cultures, contexts, and processes of knowledge management, on the other, constitute a useful conceptual rubric for the model of commensurability presented in Chapter 5. Moreover, these studies bring forward several further salient dimensions which can be applied to ontologies:

- Whether the ontology represents a relatively small and insular, or large and variegated "community of practice";
- Whether the ontology uses "expert" or "lay" vocabulary;
- What sorts of cultural beliefs, values, assumptions and practices that impact on an ontology's design;
- What sorts of contextual factors can impact on an ontology's design, and how those factors can be best rendered explicit.

As the literature review moves from an engagement with various forms of understanding social semantics towards examining computational approaches to representing and reasoning with meaning—in particular how to align different systems of meaning—the following complaint, ostensibly concerning the cognitive dissonance between ontology and broader knowledge management processes, provides a convenient segueway into the challenges at the intersection of these two fields:

> Currently, none of the ontology management tools support social agreement between stakeholders, or ontology engineers. They most often assume one single ontology engineer is undertaking the alignment, and no agreement is therefore necessary. However, the whole point in ontology alignment is that we bring together, or align, ontologies that may have been created by different user communities with quite different interpretations of the domain. Social quality describes the relationship among varying ontology interpretations of the social actors. Means to achieve social quality are presentations of the alignment results in such a way that the different alignment types are explicitly distinguished and the location of the alignments from both, a detailed and global perspective are highlighted (Lanzenberger et al., 2008, p. 109).

2.4 Computational Semantics

The question of meaning is foundational for Semantic Web and broader computational research—indeed, the problems of how to represent and reason with concepts have been central preoccupations since the earliest days of research in artificial intelligence (Norberg, 1989). Considerable attention has been devoted both to the formal, logical mechanisms for representing meaning generally, and to the construction of ontologies for representing meaning in specific fields or domains—Chapter 6, which examines different knowledge representation mechanisms, surveys some of these discussions. In the decentralised world of the Semantic Web, with no governing authority dictating *which* ontologies are useful, a corollary challenge of inter-ontology translation has led to the development of specific algorithmic techniques for automating the production of conceptual matches between ontologies. This field of *ontology matching* is explored in brief detail below. Related work in ontology metrics and collaboration are also relevant to the general approach and framework proposed here, and some recent findings are presented as well.

2.4.1 Matching Ontologies

Ontology matching aims to find relationships between ontologies via algorithmic means, where no (or few) explicit relationships exist between them; according to a recent survey of ontology matching approaches, it "finds correspondences between semantically related entities of ontologies" Shvaiko and Euzenat (2008). The fundamental problem faced by ontology matching is one of "semantic heterogeneity" (Shvaiko and Euzenat, 2008). As Halevy (2005) notes:

> When database schemas for the same domain are developed by independent parties, they will almost always be quite different from each other. These differences are referred to as semantic heterogeneity. Semantic heterogeneity also appears in the presence of multiple XML documents, web services and ontologies—or more broadly, whenever there is more than one way to structure a body of data (Halevy, 2005, p. 50).

When dealing with one-to-one semantic mappings between databases within an organisation—a familiar system integration scenario—semantic heterogeneity is typically met with round-table discussions between experts and stake-holders, who endeavour to engineer appropriate conceptual translations between schemas. This takes time: "In a typical data integration scenario, over half of the effort (and sometimes up to 80%) is spent on creating the mappings, and the process is labor intensive and error prone" (Halevy, 2005). These twin motives—time and quality—have spawned fervent searches for highly precise automatic approaches to mappings. Moreover, in the open world of the Semantic Web, where collaboration by ontology authors is often impossible, and at any rate where mappings need to be many-to-many, humanly-engineered translations may be necessary, but invariably are insufficient (Gal and Shvaiko, 2009).

Ontology matching algorithms typically take two ontologies (and possibly external data sources) as inputs, and generate a series of matches as output. A *match* consists of a tuple $< id, e, e', n, R >$, where *id* is the identifier of the match, *e* and *e'* are the two concepts from the two respective ontologies, *n* is the (optional) level of confidence in the match, and *R* is the relationship (one of conceptual equivalence, subsumption or disjointness) (Shvaiko and Euzenat, 2005, 2008). The resulting match series is termed an *alignment*. Evaluation of algorithms, given the plethora of possible inputs and evaluative dimensions, is a notably difficult task (Do et al., 2003). Since 2004, an annual competition has been held to rate algorithms outputs against expert humanly-engineered alignments across a range of fields (Shvaiko and Euzenat, 2009). Some of these approaches have demonstrated impressive precision and recall results against humanly-engineered mappings (Lauser et al., 2008; Marie and Gal, 2008), although, as Shvaiko and Euzenat (2008) note, no stand-out candidate approach has yet emerged.

In order to generate alignments, various approaches exploit the different syntactic, structural and semantic properties of ontologies. Several surveys of ontology and schema matching approaches have been conducted (Rahm and Bernstein, 2001; Do et al., 2003; Noy, 2004; Halevy, 2005; Shvaiko and Euzenat, 2005; Choi et al., 2006). Of these, Shvaiko and Euzenat (2008) provide a useful set of distinctions for grouping different approaches and methods. As with the metrics below, some of these distinctions re-surface in the presentations of dimensions in the framework in Chapter 5; hence it is useful to summarise these distinctions briefly here (redacted from Shvaiko and Euzenat (2008)):

1. *Element* versus *structure*. Element-based comparison refers to a comparison of

individual concepts. An element-based comparison might be expected to find any of the following results: that "tree" matches "tree"; that "tree" also matches the French equivalent of "arbre"; that "leaf" is a part of "tree"; that "tree" and "animal" are disjoint, etc.. A structural comparison, on the other hand, might instead compare the overall ontology graphs, or sub-graphs. Instead of relying upon individual element matches, element *relations* are also analysed. A "tree -> leaf" relation might be found to be equivalent to an "arbre -> feuille" relation, for example.

2. *Syntactic* versus *external* versus *semantic*. Both syntactic and semantic techniques use only the information contained in the ontologies themselves; external techniques may refer to other sources for information, for instance, a repository of previous matches in the same domain, or a structured dictionary like WordNet. Semantic techniques are further differentiated through the analysis of semantic relations between elements. In these cases the elements of each ontology are first normalised into a set of comparable logical propositions. If any two logical propositions from each ontology are found to have some valid semantic relationship (where a relation may be equivalent, disjointness, generalisation or specialisation), then a match is found. For example, ontology *A* may have some proposition "entity -> organic entity -> tree" [*A1*] and ontology *B* may have some proposition "thing -> life-form -> vegetable -> tree" [*B1*]. By reference to some independent set of axioms, such as dictionary (WordNet is a common choice), it can then be determined that "entity" is roughly synonymous with "thing"; "organic entity" is synonymous with "life-form"; and "tree" is synonymous with "tree". Hence the relation of equivalence is deemed to hold between concepts *A1* and *B1*.

3. *Schema* versus *instance*-based inferencing. The approaches described above refer only to the structure of the ontologies themselves, and therefore are defined as schema-based. Instance-based inferencing in contrast infers from the contents of the data the correct concepts belonging to that data. For example, some data containing a name with the word "tree"—as in "tree #35"—might be inferred as an instance of the tree class.

4. *Single* versus *hybrid/composite* techniques. Hybrid and composite techniques use a combination of the above approaches. Frequently such approaches use various weighting schemes to preference one match over others.

Since the approach adopted in this study is contrasted with algorithmic ones generally—as heuristic and holistically-oriented, rather than deterministic and atomistic—how do these distinctions differentiate algorithms particularly? Broadly it suggests that algorithms can themselves be plotted on a spectrum of "atomism–holism": the more "holistic" being those which are structural, utilise external sources, analyse semantic over syntactic relationships, and exploit a hybrid of alternative techniques (including both schema and instance-based ones). One algorithm which would rate high against these holistic criteria is *S-Match* (Giunchiglia et al., 2004). Even here, however, both the mode of analysis and outputs remain very different from what is proposed here, which is oriented towards the general cultural assumptions and beliefs, and produces a general commensurability assessment rather than specific alignments. Without prior humanly-engineered mappings to go by, the application of a culturally-oriented holistic framework is a helpful process to cross-check the alignment results generated by algorithms.

All of the algorithmic approaches discussed in the surveys so far use what Noy (2004) terms "heuristic and machine learning approaches". The other avenue towards semantic integration is through explicit mappings, where two ontologies share some common third ontology, typically asserting some set of generic and reusable conceptual axioms. Such "foundational" or "upper-level" ontologies show promise for by-passing both the time commitments and error-proneness of humanly-engineered mappings, and the vagaries of algorithmically-generated alignments. However, as Chapter 7 demonstrates, the proliferation of upper-level ontologies can create new sources of semantic heterogeneity or, in the language adopted here, incommensurability.

Why, across a given domain, are different ontologies ever produced? Relatively little account is given over the *causes* of semantic heterogeneity. Halevy (2005) offers: "Differing structures are a by-product of human nature—people think differently from one another even when faced with the same modeling goal". The resort to a kind of naturalistic individualism here underestimates socially and culturally *structural* distinctions—of the sorts discussed in the literature above—which also generate difference in conceptualisations in less stochastic ways. In the framework and case studies which follow, no single causal theory is provided to account for these differences. Nonetheless, in specific cases it is possible to hypothesise socially structural causal factors—distinctions in economic and political sub-systems, epistemological assumptions, methodological practices, the processes and uses to which these systems are put—which orient the categorial configurations of different ontologies one way or another, without reverting to a psychologism which suggests individual agents simply and inherently "think[ing] differently". By making these factors explicit, it might be possible to plot lines of potential translation and integration—or conversely, to recognise obstacles to translation irreducible to individual idiosyncrasies.

2.4.2 Ontology Metrics

Several further studies have explored metrics for describing, comparing and evaluating ontologies. Use of these metrics "are expected to give some insight for ontology developers to help them design ontologies, improve ontology quality, anticipate and reduce future maintenance requirements, as well as help ontology users to choose the ontologies that best meet their needs" (Yao et al., 2005). Some of these metrics are brought into the framework in order to characterise internal features of ontologies.

Tartir et al. (2005) propose a more extensive model for describing different features of ontologies, similar in principle to the framework presented here. They distinguish *schema* metrics, which describe the only the arrangement of concepts in an ontology, from *instance* metrics, which describe individual objects. The authors propose the following schema metrics:

- Relationship Richness—"reflects the diversity of relations" (Tartir et al., 2005), by comparing the number of non-subsumption relations to the number of subsumption relations (which stipulate specifically that one class is a sub-class of another);
- Attribute Richness—shows the average number of attributes defined per-class within the ontology;
- Inheritance Richness—"describes ... the fan-out of parent classes" (Tartir et al., 2005); in other words, whether the ontology graph is broad or deep.

The instance metrics are more extensive, but generally are less relevant for the kind of ontology comparison anticipated here. One exception is "Average Population", which describes the average number of instances or individual objects per class.

Yao et al. (2005) introduce three metrics specifically for describing the cohesion of ontologies, "the degree to which the elements in a module belong together". The metrics are: the number of root classes (NoR); the number of leaf classes (NoL); and the Average Depth of Inheritance Tree of Leaf Nodes (ADIT-LN) (Yao et al., 2005). Together these metrics provide a picture of the *structure* of an ontology—relatively low numbers of root and leaf classes, relative to the total number of classes, and, conversely, high numbers of inheritance trees suggest a high overall degree of coherence, a "deep" rather than "broad" lattice of concepts. These metrics, then, can be used to further refine the metric of "Inheritance Richness" presented by Tartir et al. (2005).

Other research has focussed on different aspects and uses for ontology metrics. Alani and Brewster (2006), for instance, discusses four distinct measures for ranking ontologies based on their relevance to search criteria, while Vrandečić and Sure (2007) discuss how to develop semantic rather than purely structural metrics, by first normalising the structure. However, the research by Tartir et al. (2005) and Yao et al. (2005) has proven to be of greatest relevance to developing generalised features which can be used to compare, as much as to evaluate, the intrinsic features of different ontologies. These metrics correspond to a number of the dimensions of the framework presented in Chapter 5, and can be used to supply quantitative values as part of the application of the framework.

2.4.3 Collaborative Ontologies

As a coda to the discussion of the technical literature on ontologies, there has also been considerable research around the idea of collaborative ontology development and matching—an area which intersects with the concerns of the argument made here. Several studies have investigated approaches and software systems for collaborative ontology development (Sure et al., 2002; Bao and Honavar, 2004; Hayes et al., 2005). In a sign that researchers are increasingly aware of social dimensions of both ontology development and matching, two noted contributors to the field have advocated:

> a *public* approach, where any agent, namely Internet user (most importantly communities of users, opposed to individual users) or potentially programs, can match ontologies, save the alignments such that these are available to any other agents' reuse (Zhdanova and Shvaiko, 2006, p. 34).

The software implementation of the framework, results of which are presented in Chapter 9, operates with similar goals, albeit with a different approach. As a tool for capturing both the implicit and explicit commitments of ontologies, the software can similarly promote reusability of the assessments of overall conceptual commensurability, and usefully augment the development of reusable conceptual alignments.

2.5 Beyond the Literature. . .

The literature review has surveyed a wide range of disciplinary studies, to develop a "four-pillared" scaffolding on which to erect a framework for comparing ontologies. In turn, the review has looked at recent discussions of meaning in relation to four themes: language, cognition, society and computation. The purposes of the review have been several: firstly, to view how meaning is treated through a series of alternative perspectival "lens", each of which reveals an important facet towards the development of comprehensive framework of commensurability; secondly, to develop a series of specific dimensions which can be used to describe and profile ontologies; and thirdly, to demonstrate that, in spite of wide-ranging studies in and around the research question posed here, both the question itself and method of answering it are unique—that the study fills a genuine gap in the literature.

The next chapter looks at methodological approaches to developing, exploring and evaluating the question. It sketches, in advance of the presentation of the framework in Chapters 4 and 5, both the general research strategy of the study, and the specific methods employed by the application of the framework.

Chapter 3

Methodology

> When the specific character of her thinking starts to come into view for us, we are not filling in blanks in a pre-existing sideways-on picture of how her thought bears on the world, but coming to share with her a standpoint within a system of concepts, a standpoint from which we can join her in directing a shared attention at the world, without needing to break out through a boundary that encloses the system of concepts (McDowell, 1996, pp. 35–6).

The first two chapters of the study have outlined the motivating questions, terms and parameters, and surveyed a sample of the wealth of literature around the pivotal topic of commensurability of knowledge systems—the *what* and *why* aspects of the research. This chapter discusses in more detail *how* the research explores these questions. The next two chapters (4 and 5) plot a framework for guiding an assessment of the commensurability of Semantic Web ontologies, and subsequent chapters (6 through to 9) apply the framework to several empirical scenarios. Here I present the strategy and rationale for the particular methods employed to test the framework. Since the framework itself includes a "methodology" component, I also discuss the motivations for that aspect of the framework here. A more programmatic description of the framework methodology is also outlined in Chapter 5, which introduces the framework as a whole.

The chapter begins by considering ontologies, a pertinent subset of the general class of knowledge systems, as objects of social research. This considerations aims to capture less the features which distinguish these systems in a technical sense, and more the connotative aspects which have accrued to them in the short history of the Semantic Web. What kinds of objects are these, and what methods are suitable to their analysis as specifically *social* artefacts? Connecting up with the discussion of sociology of knowledge and STS in the literature review, I take some cues here from other social studies of technical objects. I then provide some background to the iterative process by which the commensurability framework presented in Chapters 4 and 5 was developed. I discuss the methods by which the framework is explored, fleshed out and to some extent evaluated in practice, through a series of case studies, and an empirical pilot survey conducted on a software implementation of the framework. The concluding section voices some limitations of the methods chosen, but also states why ultimately, for the kind of prospective and exploratory models employed in this study, they are preferred over alternatives.

3.1 Ontologies as Objects of Social Research

Considered as purely sociological products, ontologies are strange objects. Since they are intended at least in part for machine processing their source format is often difficult to parse for a human reader. For example, so-called "anonymous" classes can nest expressions of arbitrary logical complexity for defining necessary and sufficient conditions for class membership. These expressions are couched in the set-theoretical operators of "union", "intersection" and "complement", and may be further constrained by rules of negation, cardinality and data typing. Syntactically, they are further obfuscated by the sometimes obscure nature of XML delimiters. Unlike taxonomies with only explicitly declared subsumption relations, then, ontologies can—in the worst, but not uncommon cases, especially in the biological domain—use logical expressions too complex to be interpreted by human agents. Indeed, handling very complex relations is one of the reasons for applying machine learning techniques to classification problems. Even armed with some knowledge of OWL and RDF semantics, analysts can struggle to understand the implicit and inferred relations of an ontology. Reasoning engines and ontology visualisation and editing tools like Protégé (Gennari et al., 2003) do offer some relief, certainly, and are indispensable for navigating and understanding their structure for large ontologies. However, the fact remains that ontologies are in the first instance objects intended for consumption by software, rather than by biological agents.

Ontologies also differ from more common software artefacts. Software code, for example, is typically comprised of instructions written in a programming language, designed to be compiled, interpreted and executed on a computational device. Ontologies are neither compiled nor executed (although they are used by executable software). They share more in common with data formats, in that they specify the form for some information content. Yet where "format" connotes something trivial and contrived—a convenient syntactic arrangement of information—ontologies are more sophisticated, conceptual entities. Like databases, knowledge bases and expert systems, they report authoritatively on the state of some slice of the world. They can be queried; and, to further discriminate them from other kinds of knowledge systems, they can utilise rich logical axioms to make possible powerful computational inferences. As noted in Chapter 1, ontologies are designed to be published into the open space of the World Wide Web, and linked, connected and integrated into a vast tapestry of concepts and assertions. Unlike traditional knowledge systems, then, their potential dissemination both imparts to them certain expectations of generalisation, reusability and intelligibility, and makes them—and the cultures responsible for them—open to public scrutiny to an unusual degree.

Additionally, the term "ontology" is also partly, and increasingly, a token used in a broader economic sphere—a way of differentiating in a marketplace a new technology from an old one. Ontologies are then more than purely technical constructs—they have a certain market value connected with a recent wave of technological innovation captured under the various rubrics of the "Semantic Web", "Web 2.0", "Web 3.0" and other monikers announcing the arrival of the technological avant-garde. Just as assuredly, the term "ontology"—in its reincarnation in the technology field—has participated in the epic journey known as the Gartner "hype cycle" (Fenn et al., 2000)—from obscurity to rapidly inflated hype to rapidly deflated disappointment through to, in turn, gradual acceptance and maturity. Understanding even something as arcane as a knowledge representation standard, then, can mean understanding something about the economic cycles of emergent technology and the subsequent dissemination of marketing vocabulary too.

As with any artefact, ontologies are products of culture. They are produced and consumed by cultures or, in more contemporary terms, "communities of practice" (Lave and Wenger, 1991). As the introductory chapters have suggested, ontologies are formalised representations of knowledge, and share many characteristics with classification systems and taxonomic structures generally. These have been studied extensively, particularly within Science and Technology Studies (STS), branches of sociology of knowledge and knowledge management disciplines. However, within these disciplines there have not emerged any definitive and canonical methods for studying such systems—ethnography, document analysis, interviews and surveys are all common and equally valid investigative techniques. More critically, there are no standardised classificatory schemes for *treating* classification systems (although particular sub-disciplinary areas, notably the library sciences, have developed quite specific meta-classificatory systems (Bailey, 1994)). Rather, each researcher tends to rely upon their own unique apparatus for describing the systems they study. While this provides considerable freedom, it also provides a source of incommensurability at the meta-level of the distinctions and classifications made *about* the classification systems under study. The method for developing a taxonomic structure here—discussed further below, and later in Chapter 5—is therefore quite syncretic, relying upon hints and suggestions culled from the literature surveyed in the preceding chapter, as well as heuristic trial and error, rather than being built upon an existing foundational system.

3.2 Towards a Framework: Rationale and Evolution

The rationale for the framework stems in part from the literature survey provided in the last chapter, which demonstrated that as yet no study had sought to apply social science research methods to the problem of ontology matching in a systematic fashion. This might be deemed insufficient warrant for the heavyweight implications of a "framework", since it could be enough simply to use document analysis, interviews or other methods to uncover background knowledge about the assumptions underlying an ontology. Indeed, much of the literature points implicitly to informal use of such methods and interpretative work in ontology matching. In practice, it was only after I had begun conducting the case studies that I saw the need to adopt a more formal apparatus for evaluating the different dimensions of commensurability which emerged in the analysis. It was apparent that attempting to evaluate the very broad question of commensurability with reference to specific data sources—both the ontologies themselves and extrinsic evidence—required some intervening layers, to move from concrete interpretation to a more abstract evaluation. I then attempted to "reverse-engineer" the informal process I had undertaken in examining different ontologies, with the eventual framework proposed here being the result.

While the framework is intended to guide a series of evaluative judgments, its construction led in turn to the question of methodology for evaluating the framework itself. Answering this question proved difficult, since I had already commenced a series of case studies, which while pointing to the *need* for a framework, proved of relatively little value in *evaluating* it. In practice the goal of evaluation was substituted by a weaker one of exploration: the case studies now function as demonstrations of the framework, and as such at least *show* that it can be applied. To further explore use of the framework outside my own personal experience, I then decided to build and deploy a software implementation of the framework that others could apply to knowledge systems. This system was then piloted among a small cohort of researchers.

In that process, several of the purposes of the framework became increasingly clear—in spite of limitations of the pilot. While there is substantial literature around social science research methods, and how to apply them to scientific and technological objects in particular, much of this literature presupposes a substantive time commitment, and in many cases, prior knowledge of social studies and theories of various kinds. Moreover—precisely because techniques like surveys, interviews and document analysis tend to be applied to all manner of research subjects and purposes subsumed under the broad category of the "social"—methods texts are understandably reluctant to prescribe pre-formulated variable sets or taxonomic groups for labeling or describing the objects of research. Indeed, the entire practice of "coding" textual content is a method in its own right (Bryman, 2004).

In this instance however, I could make several assumptions which could govern the design and justify the very existence of the framework. Firstly, it is intended to be used by practitioners with presumed technical expertise, but with no presumed knowledge of social research methods. Since the outcomes of the framework are intended to be practical—not necessarily research or academically-oriented—the framework could by-pass some (but not all) of the scruples which typically govern an introduction to research methods. Secondly, I could also assume these practitioners would be "time-poor", and seeking a relatively "quick and dirty" result—which could nonetheless be documented, and therefore justified after the evaluative fact. Thirdly, the nature of the "objects"—formalised knowledge representations—have certain constant features, discussed further below, which could permit the introduction of flexible set of variables or dimensions for describing them. Fourthly, a fortuitous side-effect in studying Semantic Web ontologies particularly (though this applies, *salve veritatae*, to other kinds of formal representations in many cases too) is that they are not only published, but very frequently discussed, designed and developed on the web—so online content analysis presented itself as an ideal "canonical" method for the framework.

Consequently it became apparent that a framework could provide a directed and convenient way to apply "agile" research methods to the study of knowledge systems, and to record observations against a pre-defined (but extensible) set of dimensions. Commensurability could further be assessed in quantitative terms by applying a weighted average algorithm to the dimension values. These three components form the basis of the framework, and are presented in more detail in Chapter 5. Packing the components as a "framework" in turn allowed me to develop software which could present the various parts described there as a coordinated whole.

The framework reached a relatively mature level of development only late in the course of the study, and by this stage the case studies were already well underway. "Re-engineering" them *post facto* appeared an impossibly difficult task, and one which moreover would obscure the gradual germination of the framework *through* the case studies. Thus, while Chapter 5 in particular precedes the presentation of the case studies, it could only be developed to its current point of maturity *via* the practical working through of them. These studies are therefore best read as embodying the early spirit rather than the mature formulation of the framework.

The difficulty of "retro-fitting" the case studies pointed to a tension in the framework itself. On the one hand, it is useful to the extent that it acts as a guide to practitioners. On the other, this guidance cannot be overly prescriptive, since even in the case studies presented here there is tremendous variability in the fields, data sources and salient evaluative dimensions and methods applied. This variation could only be exacerbated when the framework is applied by other users in other contexts to different kinds of knowledge systems. To some extent, I have tried to accommodate this variability in the framework itself. However, aspects of its presentation, especially in its eventual software form, tend to negate this idea of "suppleness" or "agility". This difficulty is examined in much more detail in Chapter 9, where the results of the software evaluation are presented.

3.3 Applying the Framework: Making the Case for Case Studies

The previous chapter surveyed several fields of research focussing specifically on the sociology, economic, historic and philosophical dimensions of science. While these differ markedly in orientation, there is considerably greater homogeneity at the level of method. The most common approach used across these disciplines—and practiced extensively in the landmark texts of Kuhn (2002), Foucault (1970), Latour and Woolgar (1986) and more recently, Bowker and Star (1999)—has been the case study. Case studies seem particularly well suited to sociological studies of science and technology since, like many of the objects they study, they too are amorphous—able to cover a brief episode or lengthy period; capable of being homogenous or heterogenous with respect to method; conducted by solitary researchers or large teams; alternatively exploratory, descriptive or explanatory in aim; in short, they can be adapted to a broad range of objects and social contexts.

A now classical reference point for describing case studies is (Yin, 2008), who provides a useful taxonomy for distinguishing various types of case studies. Yin helpfully distinguishes three kinds of investigation: *exploratory*, *descriptive* and *explanatory* (Yin, 2008). To employ a cartographic metaphor: exploration first maps out an area for study; description then details the features which appear in the landscape; and explanation points to the causal factors which generate the features. Yin points to the common misconception that case studies are at best useful for exploratory kinds of research, and argues that they can be equally valid research strategies for questions directed towards the "how" and "why"—procedural and causal dimensions—of social phenomena.

Yin also provides a useful working definition of the case study:

1. A case study is an empirical inquiry that
   - investigates a contemporary phenomenon within its real-life context, especially when
   - the boundaries between phenomenon and context are not clearly evident.
2. The case study inquiry
   - copes with the technically distinctive situation in which there will be many more variables of interest than data points, and as one result
   - relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and as another result
   - benefits from the prior development of theoretical propositions to guide data collection and analysis (Yin, 2008, p. 18).

Applying this definition to the examination of a framework for assessing the commensurability of ontologies, case studies make practical candidate research methods for several reasons:

- Here, the relationship between "phenomena"— in this case knowledge systems— and "real-life context"— the environments in which they are developed and used— is one of the key findings being sought after.
- One of the outcomes of applying the framework is the discovery of as-yet "unknown" variables, rather than the collection of "data points" against known variables.
- Often ontologies and associated knowledge systems are important intangible knowledge assets of the organisations which produce them. Even if the ontologies are made publicly available, frequently the process by which they are developed—as well as guiding assumptions—remain proprietary. Research into the assumptions behind ontologies often then needs to be opportunistic—to exploit "multiple sources of evidence", where they are available, and also to utilise appropriate methods.
- The postulation of a framework acts as a coordinating set of "theoretical propositions to guide data collection and analysis" (Yin, 2008). Even where the framework is being deployed rather than evaluated, parts of its deployment involved the generation of a set of working dimensions or variables for describing ontologies. In this context, this act constitutes the postulating of "theoretical propositions".
- The concept of a "case", which is itself difficult to define, implies some kind of bounding on the scope of research. While the case studies undertaken here are broad, in many practical scenarios scope needs to be considerably more parsimonious.
- Moreover, increasingly technological artefacts are developed collaboratively in a virtual environment. Forms of obtrusive methods—participatory or ethnographic observation—are difficult or impossible to apply to processes which unfold in the heterogenous space of the Internet.

Case studies are adopted here as the preferred strategic approach for these reasons. The aim of the case studies is to establish whether a holistic and schematic approach is useful for assessing the commensurability of knowledge systems. Towards this end, the studies need to compare and contrast two or more systems, along with their contextual conditions of production and use; in Yin's terms, the studies constitute contrastive "multiple case study designs".

Yin also provides a helpful vocabulary for distinguishing criteria for judging study findings, stressing four types of test, which are quoted in abridged form below:

- Construct validity: establishing correct operational measures for the concepts being studied.
- Internal validity: establishing a causal relationship . . . as distinguished from spurious relationships.
- External validity: establishing the domain to which a study's findings can be generalised.
- Reliability: demonstrating that the operations of a study . . . can be repeated, with the same results (Yin, 2008, p. 33).

Each of these tests can be applied to the conduct of the commensurability case studies. Construct validity can be tested by looking to see whether the kinds of differences teased out by the analysis are validly "perspectival", or rather reflect relatively trivial syntactic or semantic distinctions. Internal validity can be tested by seeking to ascertain whether differences in the systems compared are *caused* by the different perspectives in operation, or rather merely vary randomly. External validity can be tested by examining whether the usefulness of the framework is sufficiently demonstrated by the case studies, and whether this usefulness could be then extended for other cases. Finally, reliability can be tested by seeking to repeat the studies and observing whether the same results are obtained—within the broad ambit of varying subjective interpretation. The latter condition is the most difficult to ascertain, a difficulty which extends to some degree to all qualitative studies of this sort.

Notwithstanding that the exercise of the studies can be tested against these measures, it is also worth noting that in this context application of such tests is invariably also an exercise in interpretation—much as are the studies themselves. It might be argued conversely that to a large extent positive or negative test results against these measures reflect a "meta-perspectival" attitude towards the very question of perspectives themselves. In spite of these theoretical qualms, awareness and application of such measures does provide at the very least some heuristic safeguards that the framework, applied in the course of the case studies here, ought to demonstrate some utility in other situational contexts.

3.4 Elaborating a Theoretical Approach to Case Study Design

As mentioned above, case studies have been a popular research strategies for understanding scientific and technological practices. One benefit of case studies is the lack of programmatic specificity about how they ought to be conducted. In order to develop something like a reliable and repeatable procedure for assessing commensurability, however, this laudable latitude needs tempering through several methodological and structural constraints, which accordingly are spelled out and justified here.

Since the studies ostensibly analyse cases which are spatially and temporally diverse—covering different geographic regions and period of (albeit recent) history—much of the source data is documentary and discursive. Consequently, a natural fit for the evidentiary sources employed here is discourse analysis—an approach commonly adopted in other studies examining different forms of the social construction of knowledge. Keller (2005), for instance, looks at applying discourse analysis within a broader framework of a sociology of knowledge. He develops a useful, finely attenuated series of distinctions for describing the relationship between discourse and social practice, between discourse and individual language use, and between specialised and generalised discourse. He also suggests four "analytical units or concepts" for drawing together forms of discursive interpretation: interpretive schemes or frames; classifications; phenomenal structure and narrative structure (Keller, 2005). While these distinctions are useful for stretching down from the abstractions of sociology of knowledge to applied forms of analysis, they do not provide the granular navigational tools the latter task requires.

Focussing more at the level of argumentation between individual actors, Leitão (2001) presents a Toulmin-inspired model for analysing the phases of argumentative dialogue and associated epistemic transitions. As Gobo (2005) suggests, qualitative methods have only been comparatively recently accepted—and then, only in some quarters—as valid ways of doing social research. Structured computer-aided data analysis of conversation, discourse, interviews and video are helping correct the tradition bias against qualitative data analysis. This is particularly so when the original documents are published online, and so readily available to be analysed using various computer-aided qualitative techniques. Some of these techniques are applied in the case studies which follow.

The growth of the web has inspired adaptation of conventional social research methods to this medium (Schneider and Foot, 2004). These include Foucauldian-style discourse analysis of online content, as well as various forms of online ethnography, interviews and surveys, often deployed in a "multiple methodology" scenario (Bowker, 2001). As some of the studies of classification systems have shown, it is also possible to mix analysis of electronic data and systems with obtrusive, "face-to-face" methods (Bowker and Star, 1999). Recently, positioning theory—inspired by both discourse analysis and speech act theory—has also been proposed by Tirado and Gálvez (2007) as a means for studying conflict in virtual communities. The key insight of this approach is a focus on the specifically "agonal process of interaction" between members involved in a discursive space, virtual or otherwise—transposed to knowledge systems, these points of intersubjective, dramatic "agon" signify potential areas of cultural incommensurability. In their study, the authors analyse a fragment of a mailing list, teasing out the positions staked in the discourse by different interlocutors (Tirado and Gálvez, 2007). They argue that while they as analysts may disavow any privileged position in relation to the discourse they analyse, their being positioned outside that discourse affords them opportunity to demarcate a dynamic constellation of positions which emerge through a discursive "episode". This constellation constitutes not only multiple viewpoints and their respective relationships, but also represents an active configuring of power and of social order. Korobov (2001) provides a more detailed view of what positioning theory or positioning analysis might look like in a programmatic sense, distinguishing it from both conversational analysis and critical discourse analysis. Korobov (2001) adopts from Bamberg (1997) the following three levels of analysis:

- Level 1—How the conversational units (i.e. characters, events, topics, verb structure, etc.) or general conversational structure are positioned in relation to one another within the reported events;
- Level 2—How the speaker both is positioned by and positions him/herself to the actual or imagined audience;
- Level 3—How do the narrators position themselves in answering the specific and general question of "who am I?" and "how do I want to be understood". (Korobov, 2001)

Applied differentially against levels of discourse, these questions permit analysis to ascend from concrete verbal (or written) acts, through to the specific social scene in which the discourse takes place, up to the general dimensions of social order—legal, economic, political, cultural—in which individual subjectivity is located. Methodologically and theoretically, positioning analysis holds tantalising promise for the kind of discovery of assumptions behind, and positions undertaken through, the construction of knowledge systems. It also affords the possibility of systematisation, into quantitative game-theoretical models for instance, while preserving the reflexivity and context specificity of traditional qualitative discourse analysis. Since many of the materials available for researching the cultures behind knowledge systems are only available in online textual form, often couched explicitly in the form of argumentation, positioning analysis presents itself as a useful "sub-strategy" to apply within the case studies.

The approach adopted here, then, synthesises several discrete methodological elements: it blends the insights of positioning theory with those of a revitalised tradition of the sociology of knowledge, which in turn generates a theoretical grounding for a kind of critical discourse analysis Keller (2005). At an instrumental level, the nature of the "objects" treated here—both knowledge systems themselves, and the predominantly online forms of discourse about those systems—also admit the tactical use of computer-aided quantitative techniques, for counting, measuring and analysing these objects. Together, selective employment of these approaches make it possible to develop a working tool-kit which can be applied to both the technical and sociological aspect of the commensurability studies. The key elements, then, of the sociological analysis are

- Sociology of knowledge—as the overarching theoretical frame for analysis;
- Positioning analysis—as the *prima facie* method of analysing discourses;
- Computer-aided analysis—for extracting heuristic metrics and indicators from the ontologies themselves, and to a lesser degree, from the web of documents which surround them.

It is worth emphasising that these are not prescriptive elements, to be adopted slavishly, but rather act as useful directive sign-posts along the path of investigation into the question of knowledge system commensurability. Other frames, methods and techniques can be incorporated into the framework without compromising the insights resulting from its application.

3.5 An Anatomy of a Case Study: Principal Components

With positioning analysis forming a "baseline" method within each overall case study, what sort of procedures or structures guides its actual design and development? Each study here includes, to varying degrees, five basic components. The first of these is an introductory section, which contains an outline of the guiding research question, typically framed along lines of "how are systems X and Y commensurable"? The second component is a negotiable element of each study, but included here for important context and background, is an historical account outlining how the systems—and the domains described by them—arise. To portray the systems in fine relief, a technical analysis, examining each of the systems against some pre-defined metrics and indicators, follows as the third element. The fourth element is a sociological analysis, broadening the scope of the inquiry from the systems themselves to the context of their development and use—employing, canonically, positioning analysis against the available textual resources. The final component is the evaluation of the commensurability of the systems themselves, given some hypothetical situation and goal. These components are accorded differing degrees of emphasis in the actual studies which follow.

Schematically, the typical components of the case studies are:

1. Introduction—describes the knowledge systems and any known issues of translating between them, posed in a question.
2. Historical overview—background on the systems being reviewed.
3. Technical analysis of the systems, using metrics and other indicators.
4. Sociological analysis of the cultures who develop and use systems—typically, employing positioning analysis to draw out positions within available cultural discourse.

5. Assessment of the commensurability of the systems (given some hypothetical situational context and goal)—draws upon the preceding technical and sociological analysis, along with any comparative evaluations against salient dimensions, to develop an overall summary statement of commensurability.

For the study of the formal systems themselves in Chapter 6, the historical overview comprises the mainstay of the analysis. For the upper-level ontology study, the technical analysis constitutes the major part of the analysis, while for the document format study, roughly equivalent weight is given to the historical, technical and sociological sections.

In spite of these context-led variations, what emerges in each case is an overarching narrative, demonstrating in a qualitative sense the different dimensions along which translation can or cannot take place. The framework emphasises the role of context in assessing commensurability—since the context here is, at least broadly, the validity and utility of the framework itself, it might be assumed that there is a bias towards finding examples of incommensurability at the outset. Certainly in the selection of case studies, finding possible scenarios of incommensurability was a motivating factor. The role of the narrative, however, is intended to show in a more nuanced way points of both similarity and difference, which could be used in scoping the various variables—cost, time, resources and so on—involved in this or that translation scenario. Admittedly those scenarios are artificial for these studies, and so an additional strategy—the use of a software pilot, described below—has been used to provide some methodological triangulation against this concern. Aside from such issues of validity, and treated as a purely exploratory exercise, these studies also serve to demonstrate alternate paths towards making explicit key, common dimensions of commensurability—and can be further justified on these grounds.

3.6 Case Study Candidates: Finding and Justifying Cases of Incommensurability

There are several desiderata in selecting case study candidates. Firstly, both the languages, ontologies or schemas themselves, and some level of associated discourse about them, should be publicly available. Just locating two ontologies in the same field or area on the Internet is insufficient, without some further background forums, publications or other discursive artefacts which can be used to develop points of both similarity and difference between them.

Secondly, the case study should cover ontologies or schemas with largely overlapping fields or domains—in order that commensurability between them can be assessed. Although the question of commensurability can conceivably arise between ontologies with minimal or no overlap, any conclusions drawn are necessarily more tenuous. For instance two ontologies specifying concepts drawn from biology and physics respectively may also use radically different epistemic frames—but this may not be evident through any review of the ontologies of themselves.

Thirdly, the case study need not necessarily be exemplary—in the sense that it represents the *typical* dilemmas associated with matching schemas or ontologies. Rather it should show incommensurability in some conspicuous form. Using Yin's taxonomy of case studies, this criterion suggests the case study should be deliberately, selectively and even atypically extreme (Yin, 2008). Examples of this criterion can be found in Kuhn and Foucault, whose "paradigmatic shifts" and "epistemes" are, unsurprisingly, especially evident in just those studies they choose to analyse. Since the claim being tested here relates not to any ontological condition of incommensurability between knowledge systems—in which case, the selected studies would have the burden of being representative—but rather to its analytic utility, having atypical and extreme cases does not weaken this claim.

Fourthly, the case study should demonstrate the utility of the framework in some way, and also serve as a means for extending, adjusting and refining the framework, as it is presented in Chapter 5. In practice, the framework was substantially re-modeled during and after the case studies, and exhibits now a more formal appearance than would have been possible without them. The studies should nevertheless demonstrate the mature version of the framework is both consistent and productive in terms of the results they present.

Finally, the question of incommensurability exhibited by the case studies should not be simply taken as "problems" needing to be "solved", whether algorithmically or via some human-aided process. The contention here is that incommensurability, a feature always discovered in some situational context, ought not necessarily be something which ought to be eradicated. Rather it is itself a marker or indicator of some degree of radical epistemic or cultural difference which needs preserving precisely through the very process of being made explicit. The case studies ideally ought to tease out just where these points and degrees of difference arise—not necessarily through definitive isolation of explanatory, causal factors, but at least through a more systematic and justifiable description of where those differences lie.

In summary, the case studies should

1. study ontologies or schemas which are available, and also have some associated discourse about them;
2. cover ontologies or schemas with largely overlapping domains;
3. exhibit illuminating or revealing aspects of incommensurability;
4. offer some demonstration and possible explanation for incommensurability;
5. be amenable to the application of the framework discussed in Chapter 5.

Towards these various criteria, three case study candidates were selected. The first of these considers differences between formal knowledge systems—which span a range of structured data formats, information systems and knowledge representation languages—themselves. Ironically, since the Semantic Web is designed to solve problems of interoperability, it introduces new ones of its own—in particular, some degree of incommensurability with the predominant information model, the relational database. While there is considerable research and now practical products and services designed to overcome this mismatch, this case study examines in synoptic form the history of these and other candidate systems for representing information—and why any kind of proliferation of multiple overlapping systems might exist at all. The study provides some opportunity to take a longer range historical view than the other studies afford, and also provide some insight into fundamental epistemic considerations and orientations inherent in knowledge system design.

The second case study examines five so-called "upper-level" or foundational Semantic Web ontologies developed in the past decade. "Upper-level" ontologies purport to describe the fundamental existential categories, such as `Time`, `Space`, `Process` and `Entity`, in a manner not dissimilar to Aristotle's *Categories* (Aristotle, 1994) and numerous metaphysical categorial constructions since. This case study is fortuitous in that all ontologies use the same formalism (OWL—the Web Ontology Language of the Semantic Web) and cover much the same domain (though with hugely varying degrees of specificity). Each of these ontologies was developed in an academic environment, and so is accompanied by varying levels of academic publication, which provides some degree of context for the assumptions, methods and processes of their construction. Some level of both technical and sociological analysis is therefore possible, though further data about the social environment would have been highly desirable to "flesh out" the picture provided in this study. To supplement this, I examine two online mailing lists, where some of the foundational issues and debates around ontologies (in both philosophical and technical senses of the term) are discussed. This examination provides some supplementary and much-needed background to the analysis of the upper-level ontologies themselves.

The third case study looks at two emergent document format XML standards. Both standards have been ratified by ISO in recent years, and have very substantial overlap—begging the question as to why both—rather than one or the other—should have become standards. Resolving, or at least addressing, this question took the shape of a long, controversial and—within the relatively occluded space of discussion over data standards—highly publicised debate between proponents of the two standards, and many other parties—government bodies, consultants, commentators—involved in the standardisation process. Both formats embody clear, and clearly distinguishable, views as to the nature of the ontological "objects" of documents. The proliferation and ready availability of both the document specifications themselves, and the large online debate around them clearly satisfies the first criterion listed above, while the question of commensurability of the formats is front and center of the very debate itself, which capably satisfies the remaining desiderata.

Other case study candidates also presented themselves, though due to the emergent nature of the Semantic Web, and the "research" or "beta" status of many of its ontologies, the opportunities for conducting the kinds of discourse analyses applied in the cases above are relatively few. As is the tendency with new technologies, they are co-opted by "early adopters", often enthusiastic individuals or organisations for obscure or eccentric fields of application. As a consequence many prototypical ontologies do exist in fields with little or no obvious competition—a precondition for the issue of commensurability to arise. For example, modeling bibliographic records (D'Arcus and Giasson, 2009) or providing "a lightweight, subject concept reference structure for the Web" (UMBEL.org, 2009) may at some stage be of enough intrinsic appeal or commercially profitable to warrant multiple competing efforts—however, currently these are singular instances maintained by a small group of specialists.

One other area which has attracted substantial interest, research investment and even active competition has been the life sciences. Here there have been several efforts to construct biological ontologies, modeling genes, proteins and various organic taxonomic and anatomic structures. Unfortunately relatively little about this activity is evident beyond the austere academic publications which present them, and consequently it is difficult to compare the processes, methods and paradigms under which they are constructed. Alternative means of investigations—such as interviews, surveys or direct observation—would have required practical affordances of time and travel not available for this study. Nevertheless, in the first of the case studies, covered in Chapter 6, I discuss some of the reasons why the Semantic Web—and the formal ontology languages of RDF and OWL—should be particularly appealing to researchers in the bioinformatic fields. It is also worth noting that much of the research into upper-level ontologies surveyed come about through efforts to support development of biological ontologies—and so have particular leanings both towards a "natural science" epistemological orientation, and the kinds of constructs needed to support descriptions of biological objects specifically.

Finally the selection provides a useful triangulation of cases. The study of formal knowledge systems narrates the emergence of the Semantic Web (and related information models), supplying important historical context for the argument of the work as a whole. The second study tackles one area of substantial investment and development in Semantic Web technologies—the foundational axioms designed to underpin domain-level ontologies, providing the basis for interoperability between them. The third study moves from largely academic developments to the commercial interests behind document format standards. Where the first two studies necessarily engage philosophical and computer science literature as the basis for their analysis, this study permits a greater focus on a broader array of sources—blogs, comments, press releases, mailing lists and company filings. As a consequence the analysis here takes on a more conventional sociological tone. All three studies therefore provide different frames from within which to view the question of commensurability in relation to the systems analysed, and in relation to the various cultures responsible for them.

3.7 "Operationalising" the Framework: Implementing a Software System

The case studies reflect my own application of the framework, as indeed much of its development took place through the carrying out of the studies themselves. As a further examination of the framework, I conducted a pilot test with a small cohort of other users. The framework was operationalised as an online software system, which leads users through a case study of two sample ontologies, and asked them to complete a survey at the end. Chapter 9, "Framework in Practice", describes in detail the process of constructing the software and administering the survey, as well as an analysis of the results. The following section limits discussion just to the rationale for this pilot.

As exhibited by the case studies, the question of commensurability involve substantial analysis both of the knowledge systems themselves, and of background discursive materials. Several implicit findings emerged from conducting the studies: firstly, the quantitative volume of work of compiling and analysing sources and developing a narrative can be significant; secondly, the qualitative analysis of such sources is necessarily heavily interpreted via the subjective lens of the analyst; thirdly, the results are artificial and imprecise—since they are framed within an academic context. The pilot test was designed to answer the question of whether the framework could be oriented towards more practical ends by

- Using agile, "light-weight" variants of discourse and content analysis;
- Constraining interpretation through an existing set of criteria and methodological direction;
- Generating both qualitative and calculated quantitative results for the commensurability comparison.

The sample cohort was comprised of other researchers, who were likely to have had some exposure either to the specific technologies involved, or to related frameworks and approaches. This is not particularly representative of practitioners who might use the framework and software in day-to-day practice; however this group seemed ideal for a "first pass" run-through of the system, and would at any rate likely be attuned to various weaknesses in documentation, interface design, and the explanatory instruments of the framework itself. The qualitative feedback from the cohort, in particular, confirmed this suspicion.

On the whole, though, the pilot study proved a useful supplementary exercise in understanding how the framework, having been trialled on a series of case studies, might next be operationalised in practical form. It also forms a triangulating element in the case for the usefulness of the conceptual apparatus engaged in the study as a whole, oriented towards exploring the holistic commensurability of knowledge systems.

3.8 Limitations

Together the case studies and pilot evaluate provide some means of empirically validating the claims of the commensurability framework. However, several limitations are also evident.

Firstly, and perhaps most crucially, a degree of *a priorism* persists in the methods used. That is, given a particular framework—and attendant set of assumptions—it is always possible to generate certain results of varying degrees of efficacy. But there is no control test as to whether the framework and its assumptions are required to produce such results. Experienced analysts of information models, faced with data integration issues on a regular basis, might argue that expertise and practical "know-how" answer the same questions without the elaborate theoretical constructs provided here. Of course the aim of the framework is to make explicit just what sorts of tacit "know-how" might be involved—but again, other methods—interviews or surveys with experts, participant observation or long-term ethnography—might generate this kind of explicitation in a more practically grounded way.

One pragmatic response to this objection is that the relative immaturity of the Semantic Web makes sourcing such expertise difficult. Moreover, on theoretical grounds it might be argued it would be difficult to construct something like a framework *ab initio* from piece-meal empirical data collection, which at the same time stayed conceptually coherent and non-contradictory. Moreover one of the arguments made in this study is that the usually ignored or at best implicit dimensions of the question of commensurability—that is, the irretrievably social dimensions—are best teased out via application of social science methods to background sources. This may or may not prove counterfactual to the practices of experts themselves, but at any rate this argument would risk being lost if relying upon existing "best practices".

More fruitfully, it might have been possible to ask practitioners to review the constructed framework only after it had been augmented and made more robust through application to the case studies. The pilot study is a step in this direction, but the time involved in constructing the software, providing adequate documentation about the framework, and administering the pilot prohibited further steps being taken.

It might also be claimed the case studies, limited as they are, are not particularly representative of ontology or schema alignment scenarios generally. I partly respond to this above in relation to the justification of atypicality. The studies are intentionally limiting cases, which explore the commensurability question *in extremis*. More practically, Semantic Web ontologies have not permeated the main body of information technology practice to the extent that overlapping ontologies are easy to source.

Conversely, data schema integration cases are considerably easy to find, since they are an integral part of conventional IT practice. For the most part, though, organisational data schemas are usually private, and rarely published—nor are the supplementary documentary materials which have been used as the basis of these studies. Without engaging some kind of ethnographic study, then, it is difficult to gain access to the sorts of materials required.

A further twin set of concerns relate to the precision of the generated results. On the one hand, it is evident that, however constrained, a strong degree of subjective bias is involved in the commensurability evaluations (whether conducted by me, or by others in the pilot test). Given the same data, other evaluations are always possible—a fact masked by, in particular, the formulaic casting of the framework. On the other hand, for the purposes for which the framework is constructed, the results are also too imprecise. Project scoping needs a more fine-grained and detailed process for cost and time estimates. The response to these objections is that the framework can conceivably be oriented either qualitatively—to emphasise the interpretive aspects—or quantitatively— to focus on greater precision. Similarly, the scope can be scaled up—towards a Kuhn-like treatment of grander conceptual "paradigms"—or down—towards a narrow, context-bound consideration that would also focus more on the technical dimensions of commensurability. The case studies here do cover this "spread" to some extent; again, further work would be required to evaluate the framework in a range of other practical scenarios.

Some of the specific limitations relating to the individual case studies and the pilot study are treated in the relevant chapters ahead.

3.9 Towards a Theory of Commensurability

This chapter has outlined the general approach and specific methods used to develop and evaluate the framework. First, it explored the idea of investigating ontologies as specifically social objects, suggesting that this sort of activity can be subsumed within the broader category—and tradition—of "Sociology of Knowledge". There also, some points of affiliation and distinction with what has become known as "Science and Technology Studies" were put forward.

The rationale and evolution of the framework for evaluating commensurability, the core argumentative construct of the study, were then discussed. The two main vehicles used for exploring the framework empirically, comprising a series of three case studies and a software pilot evaluation, were presented. Some discussion of the limitations, and corresponding responses, followed.

In subsequent chapters the framework itself is developed and applied. Chapter 4 works through a series of philosophical positions to ground the framework theoretically. Chapter 5—the central chapter of the study—then unpacks the framework itself. The following three chapters—6 through to 8—cover each of the three case studies. Chapter 9 presents the pilot test and its results, before Chapter 10 reviews the progression and results of the study as a whole.

Chapter 4

Towards a Framework

> The freedom with the constraints of ritual logic that comes from perfect mastery of that logic is what makes it possible for the same symbol to refer back to realities that are opposed in terms of the axiomatics of the system itself. Consequently, although it is not inconceivable that a rigorous algebra of practical logics might one day be written, it will never be done unless it is understood that logical logic, which only speaks of them negatively, if at all, in the very operations through which it constitutes itself by denying them, is not equipped to describe them without destroying them. It is a question of reconstituting the "fuzzy", flexible, partial logic of this partially integrated system of generative schemes which, being partially mobilized in relation to each particular situation, produces, in each case, below the level of the discourse and the logical control that it makes possible, a "practical" definition of the situation and the functions of the action (which are almost always multiple and interlocking), and which, with the aid of a simple yet inexhaustible combinatory, generates the actions best suited to fulfil these functions with the limits of the available means (Bourdieu, 1990).

The literature review and methodology chapters open up the disciplinary and strategic paths for exploring knowledge systems against their broader cultural landscape. The present chapter discusses the question of commensurability in more theoretical terms, stepping through several philosophical positions to arrive at the basis for the framework presented in the next chapter. So far, commensurability has been about both the explicit commitments of knowledge systems, and an implicit "something" which sits behind them. But what sorts of "somethings" are these; what is it which can be said to be commensurable or otherwise? Not just the systems themselves, otherwise ontology matching techniques would be presumably sufficient—there would be no need to step outside the system to glean further information. Rather, it is the constellation of beliefs, assumptions, commitments, intentions, structures and practices held by the people responsible for those systems, who design and use them. Since people also engage in a range of other social constellations and configurations, it would be accurate to speak of the dedicated *cultures*—organisational, communal, national or global—responsible for knowledge systems. This amorphous kind of entity will be given greater specificity in Chapter 5; however its description will invariably be indebted to, and share, many of the features exhibited by canonical "structural" accounts of socialised knowledge: Kuhnian paradigms, Foucauldian *epistemes* and Quinean conceptual schemes.

The discussion of the present chapter begins, then, with a survey of these significant developments. It follows with an examination of several notable critiques of these different brands of conceptual relativism, made by Davidson and Derrida. These debates remain of central concern to contemporary theories of knowledge. Nonetheless they belong to a preceding generation of scholars; to counter with a more recent debate, the discussion embarks upon an interlude examining the "science wars" of the 1990s, via the series of critical analyses developed by Hacking. Returning to the formative problems of describing shared conceptual schemes, the discussion then presents recent theorisations by Habermas, Brandom and Gardenfors, in more detail than was afforded in the literature review. Together the positions outlined by these authors constitute an overarching theoretical scaffolding upon which a framework can be erected, rehabilitated from the relativist critiques which beset their precursors. The resulting view of conceptual cultures, interconnected through predominantly communicative practices, is not so much "poststructural"—through that epithet is employed below—as a more elastic and granular form of "structuralism". The critical resulting move is one from "conceptual relativism"—the charge laid, variously, at Kuhn, Quine and Foucault—to a form of "conceptual perspectivism", where concepts oriented within a culture do frame the view out onto the objects they observe, but critically permit a revisionary "kick-back", both from the objects themselves, and from the intersubjective communicative sphere of other cultures and agents who also observe and engage them.

A full critical exposition of any of these authors might constitute a thesis topic in itself. The apology for the abbreviated treatment offered here is only that these positions provide useful stepping stones towards the articulation of a theoretical position, which in turn provides greater specificity and robustness for the specific methods and dimensions offered in the framework description. The alternative—to do away with the theoretical artifice altogether—would set the framework adrift, as just another concocted instrument among others. It is intended that the discussion here offers the epistemological foundations, then, that orient the subsequent technical and empirical overlay that the framework and its application in the case studies provide.

4.1 A World of "Material Intangibles": Social Structures, Conceptual Schemes and Cultural Perspectives

Casting forward, Chapter 6 of the study presents a historical account of the rise of knowledge systems. Part of this account describes the flavour of logical positivism, an intellectual tradition which emphasised rigorous logical analysis and an unwavering commitment to empirical observation. This line of thought, influential in early half of the twentieth century, came under increasing critique in the post-war period. The later Wittgenstein relinquished his early normative analysis (Wittgenstein, 1921) for a descriptive exploration of language games (Wittgenstein, 1963); Austin suggested new lines of inquiry for analysing utterances beyond their purely truth-functional semantic content (Austin, 1998), instigating new dimensions for gauging their practical effect; and Sellars demonstrated the implied metaphysics which dwelt within the purportedly pure observational propositions of empiricism (Sellars and Brandom, 1997). From other angles, Marxian, Saussurean and Freudian-fueled critiques sought to expose the deep structures which lay beneath the apparent epiphenomena of social, linguistic and psychological life.

Kuhn, Foucault and Quine represent further, mature "refractions" of the harsh critical light shone on the presuppositions of the positivists. Kuhn argued that science moved not due to the irrepressible spontaneity of genius, nor the industriousness of well-managed institutions, nor, even, the inherent corrective process of Popperian falsifications endemic to scientific practice. Instead, science is a puzzle-solving exercise conducted, under normal conditions, under a "paradigm"—a set of core theoretical tenets which laid out the problems normal scientific practice could pursue (Kuhn, 1970). Foucault in turn suggested that the human sciences operated under similar epistemic structures—"epistemes"—which gave rise to a set of broadly contiguous discursive practices (Foucault, 1970). These discursive practices both participate within, and help actively constitute, political structures and techniques. In short, knowledge is power in a literal sense—it is invariably imbricated in the "political". Quine, finally, put forward a variant of the "theoretical underdetermination" thesis—that for any given set of observational data, more than one theory could be compatible with it, and therefore a theory would always remain critically underdetermined by its evidence. Prevailing theories instead do so because of the ease of their accommodation within an encompassing conceptual scheme. Each of these points to *structural* feature in the production of knowledge: paradigms change when puzzles can no longer be solved; epistemic discursive practices operate within a mutually reinforcing synergistic dynamic with power structures; rival scientific theories win out because of their fortuitous affiliation with peripheral sets of beliefs. Narratives of either the heroic individual genius—the Darwin or Einstein of their field—or of the efficient managerial enterprise—of which IBM was an early progenitor—engaging in unencumbered hypothesis testing are exposed as mythological fictions, or, at best, as radically insufficient conditions for the production of knowledge.

These kinds of structural accounts of knowledge hold considerable appeal—they permit analysis to extend beyond the surface presentation of the practices, discourses and statements which constitute the tangible aspects of knowledge. At the same time, they are materialist rather than metaphysical, showing how epistemic conceptualisations are manifest through these very tangible elements. A paradigm is just the collection of shared theories, hypotheses, puzzles, problems, experiments and data which constitute "normal science" at a point in time. An *episteme* is similarly only exhibited through the discursive practices which constitute it. A conceptual scheme is the shared beliefs held by a scientific or knowledge culture, manifest in both its utterances and practices. Yet these concepts are not mere relinquishable or interchangeable metaphors. They reference an importantly emergent property of knowledge, in which the whole is more than the sum of parts. Just as a portrait is more than the quantities and intensities of colour which compose it, these structures organise and formalise concepts, relations and properties into crystalline frames through which objects can be known. They constitute something like the perspective or world-view through which objects can be observed, inspected, analysed, described and, ultimately, acted upon. It is this material quality—that these structures allow their participating agents to reach out, through conceptual frames, to the world—that differentiates the epistemological bent of scientific and knowledgeable enterprises from other, purely metaphysical kinds of conjecture.

The next two chapters, then, introduce a vocabulary to capture the characteristics of this "material intangible" thing which is both part of and more than the knowledge systems it sits behind. These first structural descriptions, invariably directed towards sweeping periods of history rather than the micro-cultures which produce particular knowledge systems, nevertheless pave the way towards the articulation of a framework for describing this elusive entity.

4.1.1 Kuhnian Paradigms

Thomas Kuhn's *The Structure of Scientific Revolutions* systematised a thesis which had previously been only put forward informally in the earlier theories of authors such as Koyre, Polanyi and Feyerband. The proposition that science proceeds, not as an accumulation of facts which serve to inductively corroborate some theory—the classical notion of science—but as a series of paradigms which instead determine what sorts of facts may be produced, was succinctly and compellingly elaborated here. Since its publication, it has tremendous influence in the history of science, and arguably, even greater appeal through the "trickle-down" dissemination of key terms into the broader cultural lexicon. In the practice of historical and social studies of science, rival models such as Actor-Network Theory now hold sway. Nevertheless Kuhn's thesis is a pivotal moment in the widespread recognition that the movement of science is marked not only by quantitative epistemic growth but also, and more foundationally, through qualitative epistemic shifts. These qualitative shifts are described by two key concepts which warrant further exploration: *paradigms* and *incommensurability*.

Paradigms are, for Kuhn, the epistemological conditions under which the normal enterprise of science operates. They are the "ways of knowing" which makes possible the posing and solving of *puzzles*: "The existence of this strong network of commitments — conceptual, theoretical, instrumental and methodological — is a principle source of the metaphor that relates normal science to puzzle-solving" (Kuhn, 1970, p. 42). While practitioners of science exhibit a kind of "know-how" imparted by a paradigm, this does not necessarily constitute of "knowing-that" the paradigm exists; paradigms need not be, and only infrequently are, explicit: "Scientists work from models acquired through education and through subsequent exposure to the literature often without quite knowing or needing to know what characteristics have given these models the status of community paradigms" (Kuhn, 1970, p. 46). Paradigms are also the *grounding* conditions of the scientific practices they make possible, and cannot be made explicit as form of rules, statements or axioms: "Paradigms may be prior to, more binding, and more complete than any set of rules for research that could be unequivocally abstracted from them" (Kuhn, 1970, p. 46). As Kuhn (2002) notes elsewhere, paradigms have a very broad extensional definition—seeming to mean a set of both implied and explicit epistemic commitments; a meta-theoretical ground upon which more granular theories and experimental practice can be constructed; a process of socialisation—what scientists *do* to become scientists; and an historically, spatially or epistemically bounded *field*, separated from others before, after or around it. In fact each of these definitional facets permit further generous extensions in the application of "paradigm" (or its eventual cognate partner employed here).

On the one hand, following its popular usage there seems little reason to limit the use of paradigm to scientific forms of knowledge only. Other disciplinary fields—both academic and industrial—seem to meet some of not all of the qualifying features of paradigms. Management practices, for instance, operate within broad cultural conceptual models, which seem to undergo more or less radical transitions when they lose their efficacy for problem solving. Moreover, often the distinction between a paradigm of rigorous science and, perhaps, a broader paradigm of both the science and its applications are difficult to distinguish, particularly as science itself frequently bifurcates into sub-disciplinary and inter-disciplinary fields—ontology matching, introduced in Chapters 1 and 2, is a good example of a self-contained field which borrows approaches from beyond its computational science borders. Paradigms applied to clear historical revolutions—the Copernican turn in cosmology, Newton's laws of physics, Maxwell' thermodynamic equations, Darwin's theory of evolution, to take some of Kuhn's examples—show comparatively harsh lines of theoretical demarcation, and make a compelling narrative of different ways of seeing and knowing experienced through various paradigmatic lens. In the twilight world of less spectacular transitions—but no less revolutionary, for those who go through them—such lines are more blurry. Knowledge systems constitute ideal candidate expressions of more fine-grained paradigms, and as the case studies in later chapters show, these paradigms need considerably more elastic definition.

Similarly, for Kuhn—as for Foucault, further below—paradigms are invariably expressed in historical terms; paradigms succeed each other. Yet at a more granular level, different spheres of knowledge frequently coincide, compete, intersect and merge. Kuhn allows, for example, for a physicist and a chemist to provide different definitions of a molecule, based on the different paradigms they operate under (Kuhn, 1970). However, even this example assumes too rigid a distinction around an agent's paradigmatic engagement—as though one can be either a physicist or a chemist, but not both. Paradigms operating at a useful enough level of granularity to be applied to knowledge systems need to be the sorts of structures which agents can belong to *severally*, and for limited durations—enough to allow self-conscious and self-reflexive examination of the key commitments belonging to one or another co-existing paradigms. This is not an arbitrary mandate imposed here, but rather a feature of the kinds of analysis which take place in the translation of knowledge systems. System analysts, at least on an implicit, phenomenological level, frequently operate within a cognitive geometry of rotating paradigms—figuring out how to describe a concept first one way, then another; how to classify an object one way, and then another; and so on. Kuhn's paradigms all but cover these scenarios, but need to be extended down towards the "micro-paradigmatic" level to be useful here. I therefore look to carry across the insights of Kuhn's definition of "paradigm", as a general set of epistemological commitments and practices, into the theoretical dimensions of the framework, while looking to refine it into a concept more applicable to more fine-grained knowledge structures.

Kuhn also introduces the even more critical term—in the context of the present study—of "incommensurability". This term is used in the *The Structure of Scientific Revolutions* to describe how rival paradigms hold "incommensurable ways of seeing the world and of practicing science in it" (Kuhn, 1970, p. 4). As discussed below, incommensurability is a controversial term. Incommensurable paradigms suggests, literally, that propositions belonging to one are untranslatable into those of the other. By extension, these propositions are true or false only within the frame of reference of the current paradigm. Kuhn first depicts incommensurability in optical rather than linguistic metaphors. In a key chapter titled "Revolutions as Changes of World View", he works carefully to avoid the most obvious accusations of relativism:

> Do we, however, really need to describe what separates Galileo from Aristotle, or Lavoisier from Priestley, as a transformation of vision? Did these really *see* different things when *looking at* the same sorts of objects? (Kuhn, 1970, p. 120)

> I am . . . acutely aware of the difficulties created by saying that when Aristotle and Galileo looked at swinging stones, the first saw constrained fall, the second a pendulum. The same difficulties are presented in an even more fundamental form by the opening sentences of this section: though the world does not change with a change of paradigm, the scientist afterward works in a different world (Kuhn, 1970, p. 121).
>
> Rather than being an interpreter, the scientist who embraces a new paradigm is like the man wearing inverting lenses (Kuhn, 1970, p. 122).

Kuhn emphasises, over and over, how different paradigms cause scientists literally to see objects differently. The constellation of concepts which compose a given paradigm structure the observational work of science. Echoing Sellars' critique of empiricism in particular, Kuhn writes:

> The operations and measurements that a scientist undertakes in the laboratory are not "the given" of experience but rather "the collected with difficulty" (Kuhn, 1970, p. 126).

Moreover empirical data is experienced against a paradigmatic backdrop which provides a pre-existing construct for how the data can be organised and interpreted:

> All of this may seem more reasonable if we again remember that neither scientists nor laymen learn to see the world piecemeal or item by item. Except when all the conceptual and manipulative categories are prepared in advance . . . both scientists and laymen sort out whole areas together from the flux of experience (Kuhn, 1970, p. 128).

As these visual cues suggest, Kuhn wants perspectives to be incommensurable to the extent that perceived objects are organised in different conceptual configurations and constellations. In a later postscript (written after, and in response to, Davidson's critique discussed below), Kuhn asserts this incommensurability is not merely terminological, and "they cannot be resolved simply by stipulating the definitions of troublesome terms" (Kuhn, 1970). There is, on the one hand, no *immediate* language capable of neutralising these conceptual and perspectival differences:

> The claim that two theories are incommensurable is then the claim that there is no language, neutral or otherwise, into which both theories, conceived as sets of sentences, can be translated without residue or loss (Kuhn, 2002, p. 36).

Yet, on the other, there must be a way out of the solipsistic world of a paradigm. There is both the direct "stimuli" of experience, and a broader communal culture that agents under incommensurable paradigms share. This makes possible, not a neutral language, but translation between two paradigmatically committed languages:

> Briefly put, what the participants in a communication breakdown can do is recognize each other as members of different language communities and then become translators (Kuhn, 1970, p. 202).

Translation is then the vehicle which begins the process of persuasion and conversion to move from one paradigm to another. However, it is frequently insufficient:

> To translate a theory or world-view into one's own language is not to make it one's own. For that one must go native, discover that one is *thinking and working in*, not simply translating out of, a language that was previously foreign (Kuhn, 1970, p. 204) [my emphasis].

Paradigms are more, then, than use of a language—they are ways of knowing, "thinking and working". Until scientists are thinking and acting as though the world operates under Einstein's theory of relativity, they are not operating within the paradigm of relativity.

It is not clear, however, that these clarifications are adequate. In spite of Kuhn's caveats, the edges or boundaries of paradigms seem immutably hard, and nothing explains quite how, except by a process of gradual elision, an individual agent's views shift to the point of belonging to another paradigm. Yet this introduces the pain of regress to an infinity of intermediate paradigms along the way, unacceptably diluting the concept altogether. One of the steps through this difficulty is to suggest that paradigm are structures of considerably greater elasticity than Kuhn wants to allow—that "scientific revolutions" represent simply quantitatively greater shifts than other, more fine-grained changes in perspectival position. Paradigmatic incommensurability then becomes a question of degree rather than kind—a measure of "semantic heterogeneity" rather than a quality of conceptual structures.

4.1.2 Foucauldian *Epistemes*

Foucault's notion of *episteme* is more difficult to trace and delineate than Kuhnian paradigms. As Hacking (2002) notes, Foucault rarely lays out explicit definitions of concepts, nor holds on to them for long. In one of his more programmatic declarations, *The Order of Things* introduces *epistemes* indirectly as a means for describing epistemological affinities between different strands of intellectual production. To characterise the sense of the modern *episteme*, Foucault describes the rise of the classificatory disciplines—biology, economics and grammar—in the late eighteenth century:

> We have now advanced a long way beyond the historical event we were concerned with situating—a long way beyond the chronological edges of the rift that divides in depth the *episteme* of the Western world, and isolates for us the beginning of a certain *modern* manner of knowing empiricities. This is because the thought that is contemporaneous with us,

> and with which, willy-nilly, we think, is still largely dominated by the impossibility, brought to light towards the end of the eighteenth century, of basing syntheses in the space of representation, and by the correlative obligations—simultaneous but immediately divided against itself—to open up the transcendental field of subjectivity, and to constitute inversely, beyond the object, what are for us the "quasi-transcendentals" of Life, Labour and Language (Foucault, 1970, p. 272).

In this and other descriptions, several qualities of the *episteme* emerge: it is historical and, unlike a paradigm, situated across rather than within particular knowledge fields. Here, an *episteme* appears resolutely structural—a broad, temporal swathe of beliefs and practices which constitute both our subjectivity and our concepts. For Foucault, as for Kuhn, these structures affect both ways of seeing and speaking.

> What came surreptitiously into being between the age of the theatre and that of the catalogue was not the desire for knowledge, but a new way of connecting things both to the eye and to discourse. A new way of making history (Foucault, 1970, p. 143).

Later, in the more programmatic text of *The Archaeology of Knowledge*, Foucault explicitly defines an *episteme*:

> The analysis of discursive formations, of positivities, and knowledge in their relations with epistemological figures and with the sciences is what has been called, to distinguish it from other possible forms of the history of the sciences, the analysis of the *episteme*... By *episteme*, we mean, in fact, the total set of relations that unite, at a given period, the discursive practices that give rise to epistemological figures, sciences, and possibly formalised systems (Foucault, 2002, p. 211).

Further on, he elaborates:

> The episteme is not a form of knowledge or type of rationality which, crossing the boundaries of the most varied sciences, manifests the sovereign unity of a subject, a spirit, or a period; it is the totality of relations that can be discovered, for a given period, between the sciences when one analyses them at the level of discursive regularities.
>
> The description of the episteme presents several essential characteristics therefore: it opens up an inexhaustible field and can never be closed; its aim is not to reconstitute the system of postulates that governs all the branches of knowledge (*connaissance*) of a given period, but to cover an indefinite field of relations. Moreover, the episteme is not a motionless figure that appeared one day with the mission of effacing all that preceded it: it is a constantly moving set of articulations, shifts, and coincidences that

> are established, only to give rise to others. As a set of relations between sciences, epistemological figures, positivities, and discursive practices, the episteme makes it possible to grasp the set of constraints and limitations which, at a given moment, are imposed on discourse... (Foucault, 2002, p. 211).

In this later explication, the structural features of an *episteme* appear looser, more elastic. Moreover, an *episteme* is less directed towards the conceptual, and more towards the discursive properties of knowledge formation. An *episteme* here seems disembodied of the "us" which figured heavily in the description above. Rather it operates as a sort of content-less grid, a network of rules which permits certain kinds of discourse to emerge and be treated as "science" or "knowledge". Naturally there remain human agents in the background, enacting discursive practices, reading, writing and interpreting. However, these are extraneous to the construction of an *episteme*—what matters are the discursive "relations", "rules" and "regularities". These in turn stand in various relationships to other kinds of non-discursive practices, particularly those employed in the administration of power. For Foucault, clinics, asylums and prisons are the sites *par excellence*, where power-driven practices, both discursive and otherwise, intersect—and where an analysis of these practices might lead to their revision or erosion. Since "science", as a privileged form of epistemic practice, invests particular statements with a peculiar vindicating force for the exercise of power, making explicit the conditions that particularise and legitimate them also exposes them to critique:

> In the enigma of scientific discourse, what the analysis of the episteme questions is not its right to be a science, but the fact that it exists (Foucault, 2002, p. 212).

Elsewhere in interviews Foucault has also emphasised the constraining character of an *episteme*:

> If you like, I would define the *episteme* retrospectively as the strategic apparatus which permits of separating out from among all the statements which are possible those that will be acceptable within, I won't say a scientific theory, but a field of scientificity, and which it is possible to say are true or false. The *episteme* is the "apparatus" which makes possible the separation, not of the true from the false, but of what may from what may not be characterised as scientific (Foucault, 1980, p. 197).

In relation to Kuhnian paradigms, then, *epistemes* clearly have both points of affinity and divergence. Among the more notable distinctions:

- *Epistemes* relate discursive practices of a science to other practices—both other discursive practices of other forms of knowledge, and other, non-discursive social practices; paradigms remain hermetically sealed structures of a singular science.

- *Epistemes*—at least in the more explicit articulation Foucault provides in later writings—are loose, permeable structures of discursive relations; not the shared perspectives or world-views which constitute paradigms.
- *Epistemes* are framed as "rules" and "regularities" discerned by an *observer*—the "archaeologist" of knowledge; paradigms are, while still unconscious to the practitioners of science, much closer to the surface, and at least partially describable by those practitioners.
- *Epistemes* function to make possible and legitimate certain kinds of *statements* within a broader nexus of power; paradigms function specifically for "normal science" to solve puzzles—only indirectly, and coincidentally, do they engage with discourse.

There are, however, features common to both paradigms and *epistemes*: they are largely unconscious for those who engage them, and require particular interpretive tools or methods to discover them; they are not purely conceptual constructs, but also are exhibited within social practices (discursive and otherwise); both reflect social features of a culture or community, rather than an individualistic psychological state of mind; and both involve some form of "orientation" towards the objects under description—through orientation must be understood in an active sense, as actively constituting rather than merely passively observing those objects. These features carry over to the description of a more fine-grained construct in the framework ahead. Both also offer the problem of how statements can be translated across epistemic or paradigmatic boundaries—a theme returned to below.

4.1.3 Quinean Conceptual Schemes

Quine's notion of conceptual schemes fits within the generously extended family which also includes Kuhnian paradigms and Foucauldian *epistemes*. As with *epistemes*, it is difficult to get a definitive view as to what a conceptual scheme is. In a late interview Quine admits:

> The only meaning I attached to it is a vague one. Namely, the conceptual scheme would be the more abstract general structure of one's overall theory (Quine, 1992).

Echoing a famous Quinean sentiment, that science is "self-conscious common sense", conceptual schemes embrace theories of both scientific and everyday varieties (Quine, 1964). While conceptual schemes might connote a sort of cognitive structure, for Quine, they are equally "cultural posits". As theories, ultimately they have an *explanatory* function:

> As an empiricist I continue to think of the conceptual scheme of science as a tool, ultimately, for predicting future experience in the light of past

> experience ... For my part I do, qua lay physicist, believe in physical objects and not Homer's gods; and I consider it a scientific error to believe otherwise. But in point of epistemological footing the physical objects and the gods differ only in degree and not in kind. Both sorts of entities enter our conception only as cultural posits (Quine, 1980, p. 44).

Conceptual schemes of all sorts are irretrievably bound to a *language*, for Quine: "Conceptualization on any considerable scale is inseparable from language" (Quine, 1964, p. 3) He is keen to show that both linguistic translation generally, and the special kind of conceptual scheme inherent in scientific theory specifically, suffer the same fate of indeterminacy. For any set of sensory stimuli, there are many more or less meritorious theories to account for them; analogously, for any source language, there are many more or less adequate translations into a target language. For Quine, the idea of a direct "sense-datum language" capable of reporting just the facts is one of the two infamous "dogmas of empiricism", which he attributes to the more naïve leanings of positivism (the other dogma is that there can be a strict separation between analytic and synthetic statements) (Quine, 1980). Empiricism instead must be rehabituated to the *a priori* conceptual structures capable of organising perceptions, or else suffer a form of circularity: "small wonder that the quest for sense data should be guided by the same sort of knowledge that prompts it" (Quine, 1964, p. 2).

Unlike the rigid characterisation of paradigms, conceptual schemes admit of ongoing partial and "self-conscious" revision. Scientific discovery differs in degree rather than kind from other kinds of belief, precisely because it accepts revisionary evidence. Rather than the relativism of pluralised conceptual schemes, though, Quine thinks it is possible to be epistemically committed to a set of beliefs when none better present themselves:

> Have we now so far lowered our sights as to settle for a relativistic doctrine of truth...? Not so. The saving consideration is that we continue to take seriously our own particular aggregate science, our own particular world-theory or loose total fabric of quasi-theories, whatever it may be. Unlike Descartes, we own and use our beliefs of the moment, even in the midst of philosophizing, until what is vaguely called scientific method we change them here and there for the better. Within our own total evolving doctrine, we can judge truth as earnestly and absolutely as can be; subject to correction, but that goes without saying. (Quine, 1964, pp. 24–5)

The problem of under-determination does not just relate to the relationship of data to theory—it equally applies to translation of one theory to another. Multiple viable translations are always possible: "manuals for translating one language into another can be set up in divergent ways, all compatible with the totality of speech dispositions, yet incompatible with one another" (Quine, 1980, p. 27). Here it is not that the languages or theories are untranslatable; rather, they are translatable in many different ways. And it is the translations themselves which are incommensurable—"incompatible", in Quine's words—with each other. He emphasises this point with a lengthy thought experiment—what happens when a linguist is faced with some unknown language presented by an informant? The preconditions of the experiment are that there is no interpreter, and the language is not a "kindred" one for the linguist (i.e. bears no common cognates or derivations). The linguist is presented with a word, "gavagai", in the presence of a rabbit. The linguist then employs a steady process of elimination, with the aim of deriving the translation "gavagai = rabbit". One of the eventually excluded possibilities is that of equivalence based on *stimulus meaning*, the sense derived from pure experience of the rabbit-phenomenon: perhaps the word "gavagai" relates to this perception and not the actual animal? (Quine, 1964, pp. 31-5) Another is that of occasion sentences, which refer to a particular circumstance of perceiving the rabbit—is the perceiver in a state of "gavagai", then, upon remarking of the rabbit? Or is the rabbit instead in a particular state indicated by "gavagai", for example, that of being in position to be shot? (Quine, 1964, pp. 35–41) Yet another possibility is that of observational sentences: does "gavagai" relate instead to the phenomenological happening of an observation of a rabbit? (Quine, 1964, pp. 41–6) Even after these possibilities are systematically eliminated under controlled circumstances, there is no guarantee of synonymity: "Who knows but what the objects to which this term applies are not rabbits after all, but mere stages, or brief temporal segments, of rabbits?" (Quine, 1964, pp. 51) Even if the stimulus meaning—the responses of the informant hearing "gavagai" upon sight of the rabbit—is consistent with the linguist's interpretation of the word "rabbit", Quine argues that the extra-stimuli requirements for understanding the use of a term differ radically: "the whole apparatus [for using a term] are interdependent, and the very notion of term is as provincial to our culture as are those associated devices . . . Occasion sentences and stimulus meaning are general coin; terms and reference are local to our conceptual scheme" (Quine, 1964, p. 53). There is ultimately no recourse to sense data or an ideal language for devising a singular mapping between sentences or theory-fragments:

> Sentences translatable outright, translatable by independent evidence of stimulatory occasions, are sparse and must woefully under-determine the analytical hypotheses on which the translation of all further sentences depends . . . There can be no doubt that rival systems of analytical hypotheses can fit the totality of speech behaviour to perfection, and can fit the totality of dispositions to speech behaviour as well, and still specify mutually incompatible translations of countless sentences insusceptible of independent control. (Quine, 1980, p. 72)

As noted earlier, conceptual schemes seem broadly contiguous with other structural notions of paradigms and *epistemes*. Quine's critique of positivism is derived from a logical rather than historical analysis, and consequently specific kinds of historical and cultural "posits" are argued for analytically rather than demonstrated through cases. Consequently their definition is considerably abstract; nevertheless some concrete characteristics can be identified:

- Conceptual schemes are in the first instance *cultural* rather than cognitive entities;
- Conceptual schemes are *elastic*, and capable of endless revision;
- *More than one* conceptual scheme can arise to account for the phenomena being described;
- There can also be more than one *translation* between two conceptual schemes.

There are several implications of Quine's analysis for the treatment of knowledge systems: firstly, it admits the possibility both of multiple, equally valid knowledge systems in a given domain, and also, of multiple ways of aligning or matching these systems. Secondly, such systems do not describe the "sense data", or objects belonging to a domain, neutrally, but bring to bear the background cultural "posits" inherited by their authors. Thirdly, these "posits" invariably undergo revision—hence schemes should not be seen in rigid terms like the systems themselves, but a flexible networks which "cohere" into reified form in systems. Hence uncovering background concepts is necessarily a more heuristic and interpretive exercise.

These three accounts—Kuhnian paradigms, Foucauldian *epistemes* and Quinean conceptual schemes—are now "classic" structural treatments of knowledge systems in the broad sense, and deserve detailed coverage. The theoretical underpinnings of the framework developed in Chapter 5 build on these treatments, but rely on more recent work of Habermas, Brandom and Gardenfors, which adds both greater descriptive precision about what schemes are, and causal suggestiveness for how it is that multiple schemes arise. In the meantime, the specifically structural character of conceptual schemes and its analogues was to receive significant critical attention in the 1970s; two of these critical lines are reviewed in the next section.

4.2 De-structuring Critiques: Struggling with Systems, Structures and Schemes

What has been described as the "structural" tendencies in Kuhn, Foucault and Quine is more by way of general shared analogical traits than any strong identifying ideological tenets. Only Foucault could be tentatively affiliated with the intellectual movement known as "structuralism"—and was, in any case, progressively characterised as a post-structuralist in his later work. Nevertheless, as the discussion above shows, there are common threads between these authors, and indeed others of the same period. These in turn were to come under critical fire from various directions. The critiques by Davidson and Derrida are notable both from the prominence of their respective authors, and for the "anti-schematic" and "post-structural" movements to which they gave rise in various strains of linguistics, cultural studies and philosophy of language. The general outline of these critiques is traced in the next two sections.

4.2.1 "On the Very Idea"...

Davidson (2006) explicitly responds to the positions espoused by Kuhn and Quine, suggesting they represent various forms of *conceptual relativism*. Bracketing Whorfian languages and Kuhnian paradigms under the general heading of Quinean "conceptual schemes", Davidson offers a basic outline of the conceptual relativist's position:

> Conceptual schemes, we are told, are ways of organizing experience; they are systems of categories that give form to the data of sensation; they are points of view from which individuals, cultures, or periods survey the passing scene. There may be no translating from one scheme to another, in which case the beliefs, desires, hopes, and bits of knowledge that characterize one person have no true counterparts for the subscriber to another scheme. Reality itself is relative to a scheme: what counts as real in one system may not in another (Davidson, 2006, p. 186).

The inherent paradox involved in such as position is that explaining how conceptual schemes *differ* presupposes an underlying *common* language—and corresponding conceptual scheme. The act of description shows how the terms of both schemes can be mapped onto a higher level set of terms, the language of the description itself: "Different points of view make sense, but only if there is a common co-ordinate system on which to plot them; yet the existence of a common system belies the claim of dramatic incomparability" (Davidson, 2006, p. 197).

Davidson distinguishes between two "failures of translatability"— complete and partial (Davidson, 2006, p. 198). Complete untranslatability means no substantial translation between two languages; partial means some sentences can be translated, some cannot. In going after complete untranslatability, Davidson further distinguishes between the following two scenarios: the first, where speakers talk about *different* worlds using the *same* language; the second, where speakers talk about the *same* world using *different* languages. The first case makes the mistake of exercising one of Quine's dogmas of empiricism, relying upon the distinction between analytic and synthetic truths. The second case, Davidson argues, commits an analogous though different sin of relying upon a distinction between "scheme" and "content". This so-called "third dogma"—extending the two Quinean dogmas discussed above—is one which Quine himself is guilty of, as are Kuhn and other purveyors of conceptual relativism.

Davidson proceeds to argue that this dogma assumes conceptual schemes are seen as either "organizing" or "fitting in" with some "content"—in turn, such content is either "reality" or "experience". Taken actively, schemes must organize pluralities of worldly or experiential content. But such pluralities must, for Davidson, consist of observable "individualities", which in the final resort can be shown and demonstrated to other linguistic speakers, even when languages differ. In such cases, "a language that organizes *such* entities must be a language very like our own" (Davidson, 2006, p. 203). Taken passively, schemes must generate true statements of the content they purport to represent: "the point is that for a theory to fit or face up to the totality of possible sensory evidence is for that theory to be true" (Davidson, 2006, p. 204). For the thesis of complete untranslatability, it must be possible for two schemes both to be "largely true but untranslatable"(Davidson, 2006, p. 205). Davidson then invokes Tarski's *Convention T* to demonstrate that on "our best intuition as to how the concept of truth is used", translation is in fact an "essential notion":

> ... according to Tarski's Convention T, a satisfactory theory of truth for a language L must entail, for every sentence s of L, a theorem of the form "s is true if and only if p" where "s is replaced by a description of s and "p" by s itself if L is English, and by a translation of s into English if L is not English (Davidson, 2006, p. 205).

Understanding that a sentence is true in another language involves being able to translate that sentence, or a description of it, into a native language. Consequently, a theory of schemes which are mutually and completely untranslatable (or incommensurable), yet which together contain large sets of true sentences must lapse into incoherence.

The case for partial untranslatability (or incommensurability) rests upon this first result. Davidson invokes what he terms a "principle of charity"—we understand speakers of other languages (and scientific theories or conceptual schemes) by "knowing or assuming a great deal about the speaker's beliefs" (Davidson, 2006, p. 207). Accordingly, "we make maximum sense of the words and thoughts of others when we interpret in a way which optimizes agreement (this includes room, as we said, for explicable error, i.e. differences of opinion)" (Davidson, 2006, p. 207). On this view, substantial agreement needs to precede even the possibility of disagreement; rival conceptual schemes are deflated for local "differences of opinion". Less otiose, for Davidson partial untranslatability is nonetheless equally incoherent, and as a final consequence, the third dogma of empiricism—that of scheme and reality—can at this point be happily dispensed with: "In giving up the dualism of scheme and world, we do not give up the world, but re-establish unmediated touch with the familiar objects whose antics make our sentences and opinions true or false" (Davidson, 2006, p. 208).

4.2.2 The Incommensurability of Madness

Derrida's early critique of Foucault, written in 1963, is lengthy and complex, pivoting in part on a close reading and interpretation of Descartes, and of Foucault's reading of Descartes (Derrida, 2001). In broad terms it mirrors the broad structure of the critique Davidson levies at Kuhn and Quine; it is also worth noting that this critique is directed towards an early variant of Foucault's "structuralist" thought, which is revised heavily by the time of the works cited above. Rather than follow the argument in depth, I extract some salient lines of critique to demonstrate the analogy with Davidson; points which also go to the heart of the structuralist program.

In *Madness and Civilization*, (Foucault, 1965) attempts to mark an epistemic break in the eighteenth century in the dialogue between Reason and Madness. During the Middle Ages and the Renaissance, Foucault argues, madness could be publicly paraded—both literally and discursively, through the texts of Rabelais, Shakespeare and Cervantes. The Enlightenment marks the breakdown of this dialogue into two separate monologues; or rather, as madness became increasingly silenced through the general institutionalisation of rationality and the specific institutions of psychiatry, into the monologue of Reason and the silence of Madness. Foucault's project is to provide a history of that silence, to be the voice through which, retrospectively and belatedly, Madness can once again speak. Transposed to more convenient vocabulary, Reason and Madness are historically incommensurable, riven apart by the rationalist *episteme* since the Enlightenment.

Derrida's overt object of criticism is whether this project is possible and coherent—or whether, rather, in attempting to liberate Madness from its Enlightenment constraints, Foucault merely repeats the constraining gestures of Reason:

> Would not the archaeology of silence by the most efficacious and subtle restoration, the *repetition*, in the most irreducibly ambiguous meaning of the word, of the act perpetrated against madness—and be so at the very moment when this act is denounced? (Derrida, 2001, p. 41)

And later:

> Thus, not an expediency, but a different and more ambitious design, one that should lead to a praise of reason . . . but this time of a reason more profound than that which opposes and determines itself in a historically determined conflict [with madness] (Derrida, 2001, p. 51).

More obliquely, Derrida also critiques the historical structures Foucault erects, to describe the broad epistemic transitions from a dialogical—if strained—relationship between Reason and Madness towards an exclusionary one marked by the advent of the Enlightenment. At one point Derrida directs attention to the apparent arbitrariness with which Foucault cites Descartes as an exemplar of a new, emerging and ominously silencing attitude towards Madness, precisely as Reason is receiving its definitive articulation: "It is an example as sample, and not as model" (Derrida, 2001, p. 51). What epistemic status, then, does this "sample" have in a history of madness? Its representativeness of Enlightenment constructions of madness, at least, is for Derrida highly questionable.

Later, describing Foucault's project, Derrida writes:

> But I wonder whether, when one is concerned with history (and Foucault wants to write a history), a strict structuralism is possible, and, especially, whether, if only for the sake of order and within the order of its own descriptions, such a study can avoid all etiological questions ... (Derrida, 2001, p. 52)

Derrida wants to ask what relationship a singular passage from Descartes—later to be analysed in considerable depth—has to the broad historical structure Foucault seeks to account for: "Is this 'act of force' described in the dimension of theoretical knowledge and metaphysics [that of Descartes' *Meditations*], a symptom, a cause, a language?" (Derrida, 2001, p. 53) If an example does not function as either cause or effect, but simply count as a kind of suggestive evidence of the existence of a structure, what motivates its selection—and not others, in particular potential counter-examples? Although at some remove from Davidson's line of argument, there is a common concern with the relationship of the "totality" of the structure to its parts—"individualities" for Davidson, the unspecified "exemplarity" of Descartes for Derrida. A lack of methodological specificity regarding the role of exemplary parts is met by an equivalent concern voiced earlier: that different historical periods have complex, shifting and overlapping trajectories regarding the conceptual delineations they make. Consequently it is difficult to voice the history of a notion—"Madness"—which itself has undergone considerable transformation over time:

> Foucault, in rejecting the psychiatric or philosophical material that has always emprisoned the mad, winds up employing—inevitably—a popular and equivocal notion of madness, taken from an unverifiable source (Derrida, 2001, p. 49).

Just as, for Davidson, the attempt to separate content and scheme collapses—and along with it, the problem of schematic incommensurability—so, for Derrida, the various cases of conceptual and historical structures—between, respectively, the concepts of Madness and History, and medieval and classical periods of treatment of madness—are compromised. On the one hand the conceptual, structural opposition between Reason and Madness is shown to be more complicated—that trying to speak the history of a singularised entity called "Madness" risks objectifying it as an object of an historicising and alienating Reason all over again. On the other hand, the historical "structures" in which these concepts figure are shown to be less stable, and less demonstrable by way of exemplary cases, than Foucault's clear delineations might suggest.

4.2.3 Resurrecting Structures

Davidson and Derrida's critiques are of the more strenuous variety directed towards the implied relativist tendencies in any talk of conceptual structure, in either abstract or concrete historical terms. It seems anachronistic, then, to commit to untranslatable "ontological" entities such as paradigms, *epistemes* and schemes. Yet, as discussed below, geometric metaphorisations of cultural and cognitive structure continue to emerge in more recent theories. One way of avoiding the types of traps Davidson and Derrida might lay out for prospective structuralist tendencies of this sort would be to suggest such theories adopt the kinds of tempering characteristics at least implied in Foucault and Quine—to suggest that conceptual schemes are elastic, supple sorts of historical and cultural objects, without clear and rigid boundaries or demarcations. As if to help avoid this impasse, at one stage Davidson makes a crucial elision—caricaturing the relativist's position, he notes: "the test of [schematic] difference remains failure *or difficulty* of translation" (Davidson, 2006, p. 202) [my emphasis]. While Kuhn stress complete untranslatability, Quine in particular wants to acknowledge that translation is a rough-and-ready, more or less inexact and partial process, where "difficulty" need not necessarily elide into "failure". This arguably accords well with everyday intuitions about translation, even between the "micro-languages" of various organisational and cultural settings, as well as, more concretely, between the various orientations adopted within knowledge systems. And it ought to be possible to continue to think "schematically"—that is, retaining the language of conceptual schemes and structures—just so long as those schemes are treated in a suitable elastic sense. The question of commensurability can then be posed in many-valued *degrees* rather than two-valued *kind*—as a question of "how" rather than "whether" two schemes are commensurable. Moreover, schemes can be happily re-adopted having been denuded of any palpable and reified ontological form—and instead be treated as convenient bundles of particular concepts, beliefs, statements and practices of some more or less aligned group of actors. Schemes and structures, in a rehabilitated and analytical rather than ontological form, can serve a practical purpose in describing both the tacit and explicit statements of systems, and the notion of commensurability can further serve a derivatively useful function as a measure of the "difficulty" translating one set of schematic commitments into another.

4.3 Interlude: Constructions of Science

In *The Social Construction of What?*, Hacking provides a contemporary review on the kinds of positions reflected in the discussions above (Hacking, 1999). He reviews not only the by-now "classic" articulations of what has become known as "social constructionism"—through the work of Kuhn, Foucault and others—but also a series of more recent exchanges which took place over the course of the 1990s, in the course of the so-called "Science Wars". The Sokal hoax, in which a fictitious article, hyperbolically overblown with postmodern cliches, was published in a literary theory journal, supplied the catalytic impetus for the debate which followed. Hacking, in his account, is less interested in accounting for the specifics of the exchange, than in endeavouring to reconfigure the crudely bifurcated divide of "realist" and "constructionist" camps into a more finely discriminated constellation of positions.

The purpose of covering Hacking's analysis here is to demonstrate both the ongoing resonance of the theoretical issues canvassed so far, and to suggest some ways that the proposed framework can sidestep at least the more naïve excesses of relativism, if not several other related species of nominalism and constructivism. One of the risks of applying the sorts of terms adopted in this study is that it itself can be relativised to a particular cultural conceptual scheme—one which effectively mitigates its putative claims towards truth or, less ambitiously, towards usefulness. By sifting through the distinctions Hacking raises, the argument can escape with a lesser charge of "conceptual perspectivism"; a viewpoint which holds that correspondence theories of truth are usefully augmented, rather than replaced by, coherentist and consensual notions. As a consequence the theoretical underpinnings of the study would then be exonerated of the more exacting crimes of relativism and incoherence to which Davidson and others have charged some of the foundational structuralist claims laid out above.

Hacking begins by connecting the brand of conceptual relativism and social constructionism held by Kuhn, Foucault and others to an older philosophical position of nominalism:

> Constructionists tend to maintain that classifications are not determined by how the world is, but are convenient ways in which to represent it. They maintain that the world does not come quietly wrapped up in facts. Facts are the consequences of ways in which we represent the world. The constructionist vision here is splendidly old-fashioned. It is a species of nominalism. It is countered by a strong sense that the world has an inherent structure that we discover (Hacking, 1999, p. 33).

Hacking wants to show that exploded out of epithetic form, "realist" and "constructivist" positions need not entail mutually exclusive propositions. He argues that while the natural sciences can be considered as describing reality compellingly, in ways which mesh with our practical efforts to orient ourselves to the world, a degree of social construction is frequently entailed as well. Aspects of the opposition degenerate into a "two-sides-of-the-same-coin"-type of argument: : for Hacking, rather, a scientific theory can *both* be the best account of naturalistic phenomena we have—it can even be "real", "as real as anything we know" (Hacking, 1999)—and yet *equally* belong to a given historical *episteme* or paradigm, exist in a given conceptual scheme, and be socially constructed as much as any cultural or social—that is, as any identifiably *unnatural*—thing might be. This account explicates what is implicit in the theoretical overlays of Kuhn and Foucault in particular, and suggests they hold a more complicated relationship between "scheme" and "reality" than the charge of naïve, full-blown relativism often laid against them would indicate [1].

Hacking is keen to pursue a demarcation of these positions in more fine-grained terms, however. In circumscribing the field of positions identifiably constructionist, Hacking sets up a simple analytic schema of three independent variables: a theory is constructionist if it rates highly on scales of *contingency*, *nominalism*, and external explanations of *stability*. For the adamant constructionist, scientific "truths" are quintessentially contingent ones:

> The constructionist maintains a *contingency thesis*. In the case of physics, (a) physics (theoretical, experimental, material) could have developed in, for example, a nonquarky way, and, by the detailed standards that would have evolved with this alternative physics, could have been as successful as recent physics has been by *its* detailed standards. (Hacking, 1999, pp. 78–9)

The opposite side of this coin is *inevitability*—the idea of regardless who invented, discovered, studied or funded what, "*if* successful physics took place, *then* it would inevitably have happened in something like our way" (Hacking, 1999, p. 79). The inevitabilist position would claim that even some alien species, following a separate historical, linguistic and cultural path, and having embarked upon a project to discover physical laws, must necessarily have derived something like our physics; if this is the case, no amount of cultural deviation and contingency as to the superficiality of discovery change the substantive content of the discovery. Hacking cites "Maxwell's Equations, the Second Law of Thermodynamics, the velocity of light" (Hacking, 1999, p. 79) as particularly unshakeable discoveries. He then suggests that the position of the inevitabilists, unlike those of the discoveries themselves, is "not derived by inference from experience" but rather is prompted by "a sensibility that arises in a great many people in Western civilization who are attracted to scientific styles of reasoning" (Hacking, 1999, p. 79). As this quote suggests, Hacking's analysis contains a sense that at heart both contingency and inevitability theses arise from a culturally-instilled aesthetic sensibility, rather than from rational calculation. On the inevitabilist side, incompatible views are always trivially so—capable of reconciliation once the superficial contingencies of disparate lexical and observational items

[1] Rorty characterises the nature of this kind of critique in *Pragmatism, Relativism, Irrationalism*: "'Relativism' is the view that every belief on a certain topic, or perhaps about *any* topic, is as good as every other. No-one holds this view. Except for the occasional cooperative freshman, one cannot find anybody who says that two incompatible opinions on an important topic are equally good. The philosophers who get *called* "relativists" are those who say that the grounds for choosing between such opinions are less algorithmic than had been thought" (Rorty, 1982, p. 166). Rorty is here keen to separate pragmatism from the stigmatism of relativism and irrationalism. Hacking is here, I would suggest, broadly sympathetic with the kind of pragmatism Rorty advances; as the following sections suggest, Brandom forms an important stalwart for the pragmatically-inflected framework for comparing knowledge systems.

have been worked through by holders of those views. A believer in epistemic contingency permits of radically different conceptual organisations, though how this might be so would be difficult to determine in advance: “Moreover—and this is something badly in need of clarification—the ‘different’ physics would not have been equivalent to present physics. Not logically incompatible with, just different” (Hacking, 1999, p. 72).

Nominalism, the second variable Hacking introduces, is also is best understood against its more familiar opposite, which supposes that reality has an *inherent* structure waiting to be discovered:

> Even if we have not got things right, it is at least possible that the world is so structured. The whole point of inquiry is to find out about the world. The facts are there, arranged as they are, no matter how we describe them. To think otherwise is not to respect the universe but to suffer from hubris . . . (Hacking, 1999, p. 83)

Nominalism makes the opposite claim: “the world is so autonomous, so much to itself, that it does not even have what we call structure in itself” (Hacking, 1999, p. 72). Nominalists share, Hacking argues, Kant’s distinction between phenomena and noumena—the world *in itself* is unknowable. “We make our puny representations of this world, but all the structure of which we can conceive lies within our representations” (Hacking, 1999, p. 72). Words pick out groups of objects based upon what appear to be their common properties. Science, as Quine would put it, “is self-conscious common sense” (Quine, 1980, p. 3)—in light of an ever-growing body of empirical evidence, new words are coined both to identify and differentiate that evidence. Concepts thus coined are related into structures which *appear* to lay bare the hidden organisations of things—but for a nominalist, these structures are not lasting reflections of the nature they mirror, they are pragmatic tools to convey a particular understanding, to achieve a given outcome. The indeterminacy of those structures—that they could be otherwise—does not necessitate perpetual and crippling doubt on behalf of the nominalist, however, unlike the caricature which would claim “no one is a social constructionist at 30,000 feet”(Hacking, 1999, p. 67)[2]. There is no inconsistency in holding that a given arrangement of concepts allows for considerable practical feats of engineering, for example, while questioning whether that arrangement is the only one given to adequate concordance with nature.

The final variable Hacking introduces concerns explanations of scientific stability. The constructionist position here is that science is alternatively *stable* or *volatile* at times depending at least in part upon the social context in which they operate. For Hacking, the highly fluctuating states of the natural sciences in the early and middle parts of the twentieth century account for a view of science as volatile and erratic—Kuhn, Feyerabend, Popper and others were responding to unusual periods of both

[2]Both Hacking and Pinker (Pinker, 1995) quote Richard Dawkins making this claim.

scientific and political activity and turmoil, and consequently found discontinuities, anarchism and dialectic everywhere in what had previously been presupposed as a stable and cumulative exercise. The challenge now for sociologists and historians of science, states Hacking, is "to understand stability" (Hacking, 1999, p. 85), given recent decades have tended to reaffirm the glacial rather the volcanic terrain of scientific knowledge. This stability also plays into the hands of those who would like to affirm the "'objective nature of scientific knowledge [which] has been denied by Ross ... Latour ... Rorty and ... Kuhn, but is taken for granted by most natural scientists'" (Hacking, 1999, p. 88) [3]. Here "stabilists" tend to corroborate a traditional view of science as progressionist, accumulative and rational; "revolutionaries" of science affirm its epistemic and paradigmatic disruptions, generated not by internal discovery but by irrational external factors. Hacking connects these two trends with another classical distinction between rationalism and empiricism:

> Leibniz thinks that the reasons underlying truths are internal to those truths, while Locke holds that (our confidence in) truths about the world is always external, never grounded in more than our experience (Hacking, 1999, p. 91).

Hacking conveys a sense that, as with the previous "variables", the choice here is one of temperament: "rationalists, at least retrospectively, can always adduce reasons that satisfy *them*. Constructivists, with equal ingenuity, can always find to their own satisfaction an openness where the upshot of research is settled by something other than reason" (Hacking, 1999, pp. 91-2). However, there is more at stake than a simple acknowledgement of the significance of aesthetics in determining positions on the variable scales Hacking identifies. The provocations of constructivism have an important deflationary role in the institutionalising and authoritarian tendencies of modern science. In other words, Hacking recognises the structural side-effects of Kuhn and Feyerabend's critiques (Hacking, 1999)—and elsewhere, those of Foucault also (Hacking, 2002)—which cause science to re-think its ontological foundations and perhaps accept, in Hacking's terms, a "kind of objectivity ... that strives for a multitude of standpoints" (Hacking, 1999, p. 96).

What can be taken from this analysis for considering the commensurability of knowledge systems? It has already been emphasised that a simple binary opposition of "commensurable"/'incommensurable" is inadequate, and this assessment need to be treated more as scaled, multi-dimensional constructs. Hacking's three variables for describing a more general orientation towards science—contingency, nominalism and stability—also suggest a similarly scalar rather than binary application. The variables themselves, moreover, are useful in rating the standpoints of more fine-grained entities like knowledge systems; accordingly they will be carried over, in less abstract form, to the presentation of system dimensions in the next chapter. More

[3] Hacking is here quoting from Steven Weinberg

generally, Hacking's analysis goes after what he terms elsewhere "historical ontologies" (Hacking, 2002)—positions which, though framed in contemporary dialogue, in fact exhibit historical resonances with earlier articulations, similarly locked into intractable dialogical structures with their contraries. Tracing such "irresoluble differences" , all the better to "emphasize philosophical barriers, real issues on which clear and honorable thinkers may eternally disagree" (Hacking, 1999, p. 68), is not, for Hacking, an exercise in intellectual vanity, but serves to exorcise both the implacable grand-standing and "false positive" of facile reconciliations of various standpoints. There is an intrinsic sympathy, then, between his analysis here and the downstream exercise of assessing inter-system commensurability, by allowing differences to be exhumed in their various cultural refractions, and not to be merely reconciled algorithmically. The correcting factor in the case of system translation is that such differences are not presumed to be "irresoluble" in anything like an ontological sense—this judgement, too, is one contingent on the conditions of particular situational contexts in which translation takes place.

Finally, Hacking has suggested some ways out of the impasse brought about by Davidson and Derrida, by replacing conceptual "relativism" with a weaker variant of "perspectivism"—an acknowledgement that potentially irreconcilable views are organised within a historical structure of interdependent standpoints, which can in turn be analysed and made explicit against adroitly selected dimensional criteria. This insight can be applied no less to fine-grained "systems of knowledge", in the specific technical sense referred to here, as to scientific theories and indeed the whole of science itself. The next section develops this guiding insight through the theories of Habermas, Brandom and Gardenfors, who collectively provide a rehabilitated, elasticised structural account—covering social, linguistic and cognitive aspects—of conceptual schemes, which in turn paves the way for the elaboration of the framework in the next chapter.

4.4 Elastic Structures: Linking the Linguistic, the Cognitive and the Social

Habermas outlines a complex diagnostic theory of modern society which locates social pathologies in the rise of instrumental reason since the Enlightenment, and its subsequent domination over ethical and aesthetic value spheres Habermas (1987). Within the historical emergence of secularism and capitalism, this has led to the proliferation of social systems with competing ends—in the context of my argument, this proliferation spreads down to the conceptual schemes embedded within the information systems which aid in the procedural means needed to meet such ends, and is thus a major causative factor for creating conditions of incommensurability. Brandom offers an exacting analysis of language, which builds upon the insights of analytic and pragmatist twentieth century philosophy. He outlines a fine-grained theory of meaning which emphasises the normative, pragmatist, inferentialist and holist character of language Brandom (1994). For Brandom, this account runs against the general grain of twentieth century semantics, which he instead suggests offers a psychological, idealist, representational and atomistic theory of meaning. Gardenfors' work on conceptual spaces, which uses geometric metaphors to describe cognitive structures, at first glance seems incongruous against Brandom's predominantly socialised account of meaning Gardenfors (2000). Gardenfors, however, carefully reconciles concept use in individuals with a pragmatist standpoint which leads back out to the social.

These accounts are correctively adjusted to the kinds of critiques laid at the "classical" structures described above. Gardenfors' cognitive spaces are pliable and adaptable organisations of concepts, not, in this respect at least, dissimilar to Quine's conceptual schemes; Brandom's assertional structures are not the unmediated neutral language of description favoured by positivism, but sorts of trading tokens in a social "game of asking for and giving reasons". Habermas' social structures are unfortunate side-effects of an overly systematised modernity, but equally capable of interrogation and revision. These traits were certainly observable in generous readings of Kuhn, Foucault and Quine—though, as Davidson and Derrida's readings demonstrate, it is also possible to view paradigms, *epistemes* and schemes as overly reified, dogmatised and fossilised structures which suffer incoherence under scrutiny. The second "triumvirate" of theoretical positions moreover provides a suitable overlay of cognitive, linguistic and social structures through which conceptualisations can be viewed and described. For the purpose of establishing a theoretical basis for the framework which follows, then, Gardenfors provides a thorough-going and empirical theory of conceptual schemes which serves to ground the analysis presented here; Brandom develops the broad over-arching justification for connecting such schemes to the social context in which they emerge; while Habermas offers a partially causal explanation for the structural forms of these contexts, giving at least a generalised set of reasons for why rival, incommensurable conceptual schemes should arise at all in the modern era.

4.4.1 Spatialising Concepts

In *Conceptual Spaces*, Gardenfors (2000) develops a theory of conceptual representation in the cognitive science tradition developed by Rosch, Lakoff and others (Rosch, 1975; Lakoff and Johnson, 1980; Medin, 1989), surveyed in Chapter 2. Gardenfors develops a "conceptual framework", a constellation of concepts in which "concept" itself figures prominently. In the first part of the book, Gardenfors presents a framework comprising:

- *Conceptual Spaces*—a high level collection of concepts and relations, used for organising and comparing sensory, memory or imaginative experiences.
- *Domains*—a clustering of related concepts; Gardenfors (2000) suggests "spa-

tial", "colors", "kinship" and "sounds" are possible concept domains.

- *Quality Dimensions*—generalised distinctions which determine the kinds of domains concepts belong to, such as "temperature", "weight", "height", "width" and "depth". Gardenfors states: "The primary function of the quality dimensions is to represent various 'qualities' of objects" (Gardenfors, 2000, p. 6); more specifically, they can be "used to assign *properties* to objects and to specify *relations* among them" (Gardenfors, 2000, p. 6). Dimensions can be either phenomenal (relating to direct experience) or scientific (relating to theorisations of experience); innate or culturally acquired; sensory or abstract.

- *Representations*—Gardenfors discriminates between three layers of representation: the symbolic (or linguistic); the sub-conceptual (or connectionist); and the conceptual, which Gardenfors claims mediates between the other two layers. Each layer—from sub-conceptual through to symbolic—exhibits increasing degrees of granularity and abstraction of representation. Gardenfors also notes the conceptual mediates between the parallel processing of sub-conceptual neural networks, and serial processing involved in the production and interpretation of symbolic language.

- *Properties*—are means "for 'reifying' the invariances in our perceptions that correspond to assigning properties to the perceived objects" (Gardenfors, 2000, p. 59). They are specialised kinds of concepts which occupy a "region" within a single domain, delineated within the broader conceptual space by quality dimensions. A feature of properties defined in this way is that they accord both with strict and vague or fuzzy borders between properties—objects can be permitted "degree[s] of membership", depending upon their proximity to the centre of the property region. Both classical and prototypical theories of classification can be accommodated.

- *Concepts*—General (non-propertied) concepts differ from properties in that they can belong to multiple domains, and different conceptual features can gain greater salience in different contexts. Concepts are in a constant process of being added, edited and deleted within new domain arrangements; consequently, concept meaning is transient. Conceptual similarity comes on the basis of shared or overlapping domains.

The resulting framework is pragmatic and "instrumentalist"; the "ontological status" of conceptual spaces is less relevant than that "we can *do* things with them" (Gardenfors, 2000, p. 31). Specifically, the framework ought to have "testable empirical consequences", and further, to provide a useful knowledge representation model for "constructing artificial systems" (Gardenfors, 2000, p. 31). One advantage of the use of geometric metaphors to describe conceptual arrangements is that it is possible to calculate approximate quantifications of semantic distance, between both individual concepts and concept clusters. However, the mathematisation of conceptual structures is to be taken as a heuristic rather than deterministic model—for Gardenfors, "we constantly learn new concepts and adjust old ones in the light of new experiences" (Gardenfors, 2000, p. 102). In light of this every-changing configuration of concepts, any calculation of semantic proximity or distance is likely to be at best accurate at a point in time, although statistically—across time and users of conceptual clusters and relations—there may well be computable aggregate tendencies.

The arrangement of concepts and properties within conceptual spaces and domains depends upon a coordinating principle of *similarity*:

> First, a property is something that objects can *have* in common. If two objects both have a particular property, they are *similar* in some respect . . . Second, for many properties, there are *empirical tests* to decide whether it is present in an object or not. In particular, we can often *perceive* that an object has a specific property or not (Gardenfors, 2000, pp. 60–1).

Dimensions form the basis against which similarity is assessed—a single dimension for properties, multiple dimensions for concepts. Conceptual similarity for Gardenfors is intrinsically a cognitive and theoretical notion, however, which can consequently be varied as different dimensional properties are found to be more or less salient:

> For example, folk botany may classify plants according to the color or shape of the flowers and leaves, but after Linnaeus the number of pistils and stamens became the most important dimensions for botanical categorizations. And these dimensions are perceptually much less salient than the color or shape domains. Shifts of attention to other domains thus also involve a shift in overall similarity judgments (Gardenfors, 2000, p. 108).

In the latter part of the book, Gardenfors then shows how his framework can be applied to traditional problems of semantics, induction and computational knowledge representation and reasoning (Gardenfors, 2000). In particular he emphasises the relationship of conceptual structures to broader spheres of human action and practice. In what is an avowedly "pragmatist account", meaning is put to the service of *use* within these spheres—though it is not equivalent to it. Unlike conventional semantics, the kind of "conceptual semantics" Gardenfors espouses works down from social practice to fine-grained linguistics utterances:

> . . . actions are seen as the most basic entities; pragmatics consists of the rules for linguistic actions; semantics is conventionalized pragmatics . . . and finally syntax adds markers to help disambiguate when the context does not suffice (Gardenfors, 2000, p. 185).

The pragmatist elements of this account fits well with the analysis of language Brandom undertakes, while the social orientation begins to bring concepts both out of mind and language and into the intersubjective domain theorised by Habermas—points of accord succinctly encapsulated in the following quote: "In brief, I claim that there is no linguistic meaning that cannot be described by cognitive structures together with sociolinguistic power structures" (Gardenfors, 2000, p. 201). Applied to knowledge systems, Gardenfors supplies a convenient "first tier" description of the kind of entity which both includes the explicit conceptualisation of the system itself, and the tacit commitments which stand behind it. "Conceptual spaces", standing here for Quine's "conceptual schemes", are mentalist metaphors for describing at least part of what it is that a knowledge system represents. The remaining sections add further descriptive tiers upon which the framework of the study can be mounted.

4.4.2 Practicing with Concepts

Brandom develops a contemporary account of linguistic practices grounded in the pragmatist tradition of Sellars and Rorty. Unlike Rorty, for whom all kinds of linguistic utterance were of equivalent functional significance, Brandom privileges propositional *assertions* as "fundamental speech acts", without which other speech acts—commands, interrogatives, exclamations—would not be thinkable (Brandom, 2000b). Assertions are, for Brandom, tokens in a "game of giving and asking for reasons", nodal components in a vast articulated web of *inferences* which constitute discursive practice. The primary role of assertions is not, as a correspondence theory of truth would have it, to represent an actual state of affairs, but rather to express, or, in Brandom's more canonical expression, to make "*explicit* what is *implicit*" (Brandom, 2000b). In a pivotal passage, he continues:

> This can be understood in a pragmatist sense of turning something we can initially only *do* into something we can *say*: codifying some sort of knowing *how* in the form of a knowing *that* (Brandom, 2000b, p. 8).

Where Gardenfors' primary linguistic unit of analysis is the word, for Brandom it is the sentential structure that provides the key to "knowing *that*", to assertion-making. An atomistic orientation towards concept-use might make it appear that concepts are accumulated, one after another. For Brandom, *contra* Davidson, the *scheme* necessarily precedes the individuated concept:

> One immediate consequence of such an inferential demarcation of the conceptual is that one must have many concepts in order to have any. For grasping a concept involves mastering the proprieties of inferential moves that connect it to many other concepts . . . One cannot have just one concept. This holism about concepts contrasts with the atomism that would result if one identified concepts with differential responsive dispositions (Brandom, 1994, p. 89).

Brandom's implied broad swipe here is directed towards a whole semantically formalist tradition whose origin he locates in the work of the later Frege (his reading of early Frege is considerably more commensurate with the inferentialist, expressivist and pragmatist line Brandom himself adopts). Demonstrating how sentences, and sub-sentential devices such as anaphora, primarily function to relate concepts within an inferentialist network of reasons take Brandom much of the 741 pages of his landmark *Making It Explicit* (Brandom, 1994). At the heart of Brandom's enterprise is an attempt to reconcile the rigour associated with this formalist tradition with a more appropriate philosophically holistic orientation, which sees assertional speech acts within a broad tapestry of human action and "social practice" generally. This has clear resonance with this particular project; although Brandom addresses neither the question of translation nor of knowledge systems specifically, several inferences can be drawn from his analysis:

- Knowledge systems utilise formal languages, which for Brandom differ by degree rather than kind from natural languages. A fundamental feature of a knowledge system remains that of making assertions and "giving reasons". The very purpose of employing such systems, with an underlying logical apparatus, is precisely that of deriving conclusions from a set of axioms using an explicit chain of reasoning.

- More generally, the systems themselves stand as discursive practices with a general game between, typically, more course-grained sociological entities than individual actors—organisations, departments, and other cultural groups.

- The semantically holistic and expressive orientation towards knowledge systems can direct attention not only towards the existing "knowing-that' s" asserted by the systems themselves, but also towards both the background "knowing-how' s" and "knowing-that' s"—the *practices* and as-yet unexplicated conceptual commitments—of the cultures responsible for them.

- Finally, translation itself consists of a series of assertions; that concept A is synonymous with concept B, for example. The act of translation therefore entails its own "circumstances and consequences of application" (to invoke another Brandom idiom). Recognition of the situational context of the translation direct attention towards just what circumstantial and consequential conditions impinge upon those assertions.

A further note relates to the specific treatment of structure in Brandom's work. The entire practice of making, interpreting and reasoning with assertions stands within what he terms an "*I-thou* deontic score-keeping" relation. This, for Brandom, is "the fundamental social structure" (Brandom, 1994). This base structure operates like a simplified, idealised model, in which two interlocutors are locked into a game, metaphorically tabulating each others' reasons offered for actions, practices, commitments, beliefs and attitudes. This theoretically endless activity does not yet offer an account for how some series of disagreements might grow into schemes which are incommensurable. To explain this—without falling prey again to Davidsonian lines of critique—requires a shift in registers, from what appears fundamentally a psychological inter*subjective* scenario—between two well-intentioned agents—to a sociological one—between two *cultures*, whose intentions are never quite irreducible to those of the agents who represent them. To make this shift the next section draws upon an essential Habermasian distinction, between *lifeworld* and *system*, which offers explanation for how more fundamental rifts in the social tapestry might occur.

4.4.3 Socialising Concepts

Where Gardenfors and Brandom acknowledge the role played by the social sphere in structuring conceptual arrangements, neither provide an account of what sorts of structure are germane to this sphere itself, nor what might cause rival conceptualisations to emerge. Kuhn and Foucault had developed explanatory theories of sorts but, at least in the case of Kuhn, these theories were limited to a particular domain of the social—the scientific domain. While no encompassing causal theory might adequately account for all variations in cultural conceptualisations—or less abstractly, differences in how cultures see the world—a theory which at least makes perspicuous some common lines of demarcation would be helpful. Foucault's later analysis of "micro-power" goes some way in this direction, yet he consciously abjures any abstract generalisable theorisation (Foucault, 1980). Bourdieu's elaboration of "habitus" is similarly useful at an intra-cultural level (Bourdieu, 1990), but is not directed oriented towards an explanation of the sorts of inter-cultural differences which might arise, particularly within the "networked societies" engaged in information system development and use (Castells, 1996).

Habermas is sometimes taken as being either a theorist of "incommensurability" (Latour, 1993) or, at others, its exact opposite: a naïve advocate for an idealised "communicative rationality" directed towards utopian understanding (Flyvbjerg, 1998). The interpretation offered here suggests he represents neither of these extremes, but rather a Kantian rationalism despondent—on the one hand—at the over-systematisation and objectification of modernity, yet conciliatory—on the other—towards the potentials of dialogue and communication for redressing this trend. As with the other theorists encountered here, there is insufficient scope for any kind of thorough treatment of Habermas' full theoretical apparatus. Instead I focus attention on a pivotal conceptual opposition: between *system* and *lifeworld*, outlined in *The Theory of Communicative Action* (Habermas, 1987).

For Habermas, the Kantian trichotomy of instrumental, ethical and aesthetic rationality are ontologically primary categories of modernity. These broadly correspond to objective, inter-subjective and subjective spheres of individual experience. Habermas inherits the critical lines of Weber, Lukacs and the Frankfurt school towards post-Enlightenment reason, which has missed its potential to act as a liberating tool. Instead it has been co-opted within specifically modern configurations and systems of power and oppressive administration (Horkheimer and Adorno, 2002; Adorno, 2001). Rationalisation has been operationalised as an *instrumental* process within *all* spheres of human experience—everything has been subjected to systematised logic. Even individual subjectivity, what for Kant ought to remain the inviolable sanctuary of private experience, has been externalised, publicised and rendered transparent to the machinations of modern systems—through, for example, the various concrete vehicles of the media, the professed wisdoms of popular psychology, the endless commodification of art, and the cult of celebrity. For Habermas, as for critical theory, this outgrowth of hyper-rationalisation has a corresponding corrosive and pathological effect on the "lifeworld"—the phenomenological horizon experienced by individual subjects. Paradoxically, the domination of a singular form of rationality has also led to a fracturation and destabilisation of a social world into multiple *systems*. Such systems—at a macro levels, these include legal, economic, scientific and political systems—operate according to the internal dynamics of their particularist ends, and remain only loosely, if at all, coordinated within a social whole. Accordingly, conceptual schemes are segregated in a profound way within the system spheres in which they are engaged. Habermas describes this development:

> At the level of completely differentiated validity spheres, art sheds its cultic background, just as morality and law detach themselves from their religions and metaphysical backgrounds. With this *secularisation of bourgeois culture*, the cultural value spheres separate off sharply from one another and develop according to the standards of the inner logics specific to the different validity claims ... In the end, systemic mechanisms suppress forms of social integration even in those areas where consensus-dependent coordination of action cannot be replaced, that is, where the symbolic reproduction of the lifeworld is at stake (Habermas, 1987, p. 196).

However, this historical diversion is not irrevocable within Habermas' schema; the very conditions which effect the outgrowth of a particular form of rationalisation can also serve to corral it within its proper sphere of operation—that of scientific knowledge of the world. Provocations from the subjective sphere of experience, such as various inflections of Romanticism, are insufficient for this containment and merely serve to buttress the over-extended reach of systemic reason. Rather it is the intersubjective sphere, where human agents engage in communication and dialogue, where reason can be directed not towards the achievement of specified functional ends, but towards the formation of social consensus, that functional ends can be re-evaluated within the context of society as a whole. The derivation of consensus through the pure consideration of better reasons—a never fully realised process, but nonetheless operating as a counterfactual ideal—acts as a mediating force between the private wants of subjective selves and the oppressive operations of hyper-rational systems of modernity. For Habermas communication offers the potential to arrest "*the uncoupling of the system and lifeworld*" and return from "the threshold at which the mediatization of the lifeworld turns into its colonization" (Habermas, 1987).

Habermas' analysis can be seen to supply the missing detail to Brandom's reference to the "the social", which is posited as an "unexplained explainer" in his account. The connection between Habermas and Brandom is not seamless, as a recent exchange attests. Despite many points of intersection, they differ precisely over the question of whether Kantian trichotomy precedes or is instead subject to the role of logic and inference—Brandom insists, contra Habermas, that specific domains sit downstream from the primordial experience of "asking for and giving reasons" (Brandom, 2000a). Broadly, though, Habermas can be seen as having developed an important and encompassing explanatory account of how specific schemes can be *incommensurable*. In spite of how language appears, even in the work of Brandom, to be an undifferentiated tool for establishing lines of inference between co-operative agents, social systems have in the course of modernity increasingly operated according to local teleological programs—programs which, through the operationalisation of specific language games and jargon, serve to blunt language's more incisive communicative potentials. Within the "iron cages" of technocratic institutions, inter-system "interfacing", using perfunctory rational procedures, has replaced genuine intersubjective dialogue. Within these differential ends and parametric conditions, unique morphologies of organisational cultures generate different conceptualisations of common entities. Even conceptualisations which are externalised and globalised—in the form of technology standards, for example—are typically adopted via rationalising fiat, either via conformance to *de jure* fiat or recognition of *de facto* network externalities—rather than because of an internally deliberated conclusion brought about by the force of better argument.

Unlike the accounts examined above, it is not a foregone conclusion that the conceptualisations produced within these spheres be radically incommensurable however—only that it is possible to diagnose the potential causes, along lines of different cultural ends, procedures and intentions, when they are. Moreover the efficacy of idealised dialogue, of the kind both Habermas and Brandom are happy to countenance, and towards which actual communication constantly strives, can assuage the rougher edges of translation in practice. Brought back down to the technical domain of knowledge systems—and in lieu of any active participation between the cultures responsible for them—the role of the analyst is to ferret out both the points of differentiation and the potential conciliatory paths between them. This involves, practically, identification of salient dimensions against which such points and paths can be plotted, and a corresponding process of interrogation of the cultures responsible for the systems under review.

Habermas, then, does not endorse a romantic yearning for an over-arching metaphysics, a stable social order or a single governing conceptual scheme. Nor does he champion endless devolution into more granular, localised and ultimately untranslatable systems of meaning. His aim is rather to recuperate the promise of Kantian rationality by recalibrating the obsession of modernity with instrumental reason by emphasing the equivalence of ethical and aesthetic spheres. In practice this allows systems to proliferate in their respective manifold differences, but never so far as to negate the potentials of translatability and commensurability completely. Further consideration of the greater Habermasian project would take this discussion too far afield; here it suffices to provide a sociological and historical explanation of causative factors in the *in*commensurability of conceptual schemes, and thus serves to connect up Brandom's pragmatist analysis of linguistic meaning and Gardenfors' analysis of conceptual spaces to a broad historical context. Together these connections—linking up the linguistic, the cognitive and the social—develop an altogether more fluid and elastic conception of "structure", one avowedly informed by materialist and pragmatist concerns, than those advanced by the earlier generation of theorists discussed above. A path has now been prepared for the description of such a rehabilitated structure, as it relates more directly to knowledge systems and the cultures responsible for them.

4.5 Towards a Framework. . .

The early sections of this chapter outlined three broadly commensurate positions which can be broadly subsumed under the title of "conceptual perspectivism". Though Foucault goes much further than Kuhn and Quine, little is articulated in these positions about *why* different perspectives take form—just *that* they do. Accordingly, these positions are all open to charges of relativism and incoherence, which Davidson and Derrida lay out powerfully. Hacking moves to outline a more nuanced position in the context of the recent "science wars" of the 1990s, which demonstrates something of a dialectal force which motivates the staking out of positions and perspectives within, at least, the scientific domain. He demonstrates how the traditional debate between realism and nominalism has been resurrected in these contemporary discussions.

Habermas then supplies a more directed account—historically grounded and materialist in orientation— for how perspectives emerge and acquire currency through communicative practices. Brandom supplements this account with a more finely-tuned analysis of linguistic utterances—paradigmatically, assertions—and how such utterances operate as more literal tokens within a dialogical game of "giving and asking for reasons". Playing the game—requesting and making assertions—offers language users endless opportunities to revise and correct a holistic conceptual network. Gardenfors, in turn, provides a more granular account still of the kinds of things which constitute a conceptual scheme—concepts, relations and properties—within an ostensibly pragmatist framework. Together these theories can be pieced together to formulate an explanatory device for conceptual schemes which is neither relativising nor succumbs to a purely representationalist thesis—"the myth of the given", in Sellars' words. In short, it is possible to construct upon these theoretical underpinnings a framework which embraces correspondence, coherentist and consensual notions of truth. Or, in other terms, it ought now be possible to describe a framework which examines conceptual translation in terms of denotation—whether two concepts refer to the same objective things in the world; connotation—how two concepts stand in relation to other concepts and properties explicitly declared in some conceptual scheme; and use—or how two concepts are applied by their various users. Moreover there is flexibility within the framework to lean towards either "realism" or "nominalism", since both can be accommodated—with varying degrees of approximation—within the kind of materialist and pragmatist orientation now developed.

Chapter 5

A Framework for Commensurability

> S: But you always need to put things into a context, don't you? P: I have never understood what context meant, no. A frame makes a picture look nicer, it may direct the gaze better, increase the value, but it doesn't add anything to the picture. The frame, or the context, is precisely the sum of factors that make no difference to the data, what is common knowledge about it. If I were you, I would abstain from frameworks altogether. Just describe the state of affairs at hand (Latour, 2004, p. 64).

This chapter outlines a model for assessing the commensurability of knowledge systems, and of the cultures responsible for them. It represents the culmination of the theoretical development of the idea of commensurability so far. The introduction outlined the general parameters and questions of the research; the literature review surveyed in broad brush strokes disciplinary views of semantics, and some of their points of intersection; the methodology outlined the approach taken towards exploring the research questions, and Chapter 4 worked through several contemporary views on cultural conceptual schemes, with the aim of developing a theoretical foundation for the key concepts presented in the framework here.

In constructing a framework for assessing commensurability of ontologies, this chapter cements these argumentative levels together. It presents, firstly, a speculative theoretical model, derived in large part from the literature review and theoretical analysis (Chapters 2 and 4 respectively), of what it is that is being investigated in a commensurability assessment—what sort of entity underpins a formal knowledge system. Then the framework itself, designed to profile and explore differences in these systems, is described. The framework comprises a) a model of an idealised commensurability situation, where two systems are to be aligned; b) a series of dimensions for evaluating the cultures responsible for those systems; c) a quantification of the assessment; and d) a procedure for applying the dimensions and interpreting the results. Collectively these tools form part of an analyst's toolkit for evaluating the degree of fit between two knowledge systems.

The next four chapters apply the framework in different ways. Chapters 6 to 8 apply the framework in the form of several case studies. These include: a comparative study of formal knowledge systems themselves, notably the relational database and the Semantic Web; a review of upper-level or foundational ontologies; an analysis of a recent controversy over the standardisation of document formats; and the results of a pilot study of a software implementation of the framework.

5.1 What to Measure—Describing "Ontological Cultures"

The argument has developed to a point that it is possible to put forward a model of the kinds of conceptual entities which are both explicit in knowledge systems themselves, and implicit in the practices and beliefs of the people who design and use them. These "entities" have so far been described through a series of near-cognate, proximally synonymous terms, ushered in throughout this study to denote both a given system or arrangement of concepts, and on occasion, also the social environment, and the people who produce and consume them. Yet none of these terms—*perspectives*, *world-views*, *paradigms*, *epistemes*, *conceptual schemes or spaces*, *historical ontologies*, *lifeworld*, *habitus*—seems quite adequate for the kinds of entities wanted here. The following account aims to characterise these entities in descriptive terms, before then offering a formalised account as a part of the framework further on below. The account may seem more dogmatic that is intended; just as Minsky notes in a similar framework endeavour, this account proceeds while "pretending to have a unified, coherent theory" (Minsky, 1974).

What is envisioned here, then, is an elastic, dynamic, fluid yet interconnected "structure" shared across members of a group or organisation; neither a subjective, individual cognitive "lifeworld", nor a stable, socialised epistemic "system", but something at an intermediate and intersubjective level of granularity. "Conceptual scheme" seems adequate though insufficient, as the sought-after concept must also embrace the structural conditions and social practices which give rise to such schemes. Stopping at the conceptual misses out on these elements. A more embracing term is needed, which directs attention out from subjective cognitive abstractions towards the objective and intersubjective spheres in which those abstractions are generated, and to which they correspond.

"Culture" is one possible term; it both signifies a collective group and, more remotely, connotes a homogenous, self-replicating organism. The term has the advantage of being at the right granular level, since it is elastic and can be stretched and scaled along several dimensions—it can describe a large or small, short or long-lived, casually or formally, historically or spatially organised collective of individuals. One of the functions of the cultures considered here, though, is that they produce very particular kinds of artefacts—formal knowledge systems. To describe just those cultures engaged in the production of knowledge systems particularly, I have added the epithet "ontological". Taken literally, an "ontological culture", then, is something which produces formal knowledge systems like Semantic Web ontologies—organisations, communities, and other social groups who, as one of their practices, organise slices of the world into classificatory schemes. More tenuously, "ontological culture" can also be taken in several other senses too: a culture which, to coin a neologism, *ontologises*; actively constituting its world and the beings in it (meaning something similar to Hacking's use of the phrase "historical ontology"); or even as a biological "culture", which is differentiated from more mundane microbial kinds of culture by being "ontological" in the philosophical sense. The conjoined term, as a result, operates as a weak double pun, implying each of these meanings. Though concisely descriptive, this term does however strain at convention use; occasionally through the study the more conventional term of "knowledge cultures" has been preferred—though lacking in specificity the latter term also has an existing resonance in the sociology of knowledge and science (for instance, (Knorr-Cetina, 1999; Peters and Besley, 2006)).

An "ontological culture" inherits many of the characteristics ordinarily assigned to cultures generally. The remainder of this section presents a basic narrative, unfolding a series of terms as it develops a description of "ontological culture". These terms, in turn, are formalised into a more coherent model which is employed in the more technical discussion of the framework further on.

The organic connotation of "culture" implies a certain autonomy—that cultures are, like Luhmannian systems, first-order *sociological*, rather than psychological or biological entities. They are in some sense irreducible to the agents or actors who comprise them. Actors instead perform semi-deterministic roles in accordance with the functional goals of a culture, of which there can be many: for example, generating profits, delivering services, providing welfare and conducting research. A typical overriding goal is one of self-maintenance—one of the ways it achieves this goal is by replicating its beliefs and practices. This may happen in a more or less predatory fashion, and in part takes place through communicative practices which have the intended effect of norming participating agents—of fostering adherence to beliefs and practices. In a general sense, having goals gives a culture a quality of intentionality—its practices are directed and goal-oriented, much as those of a biological agent might be. Retaining the organistic analogy, cultures reproduce, evolve, inhabit spaces, communicate with other cultures, and ultimately expire. While analysable and modelable, this cultural activity is partly stochastic, predictable only within broader, non-deterministic and probabilistic parameters.

A culture also operates within a general environment—what it sees as its "world"; or, in Habermasian terms, its "lifeworld" (*Lebenswelt*). This environment supports other cultures; cultures can stand in structural relations to one another. Cultures can even be nested; for instance, when a greater culture harbours an embedded revolutionary cell. The relationships within and between cultures constitute semi-porous, permeable networks — sub-cultures, cross-cultures or "hybrid cultures" are all examples. These structural delineations and permeations can be traced through the practices enacted within those cultures—canonically, within discursive practices. Discursive practices produce epistemic artefacts—representations of knowledge—which reflect the perspectival orientation of the culture towards the objects it encounters—or engenders—in its world. However, a perspective is not fixed—it reflects a point-in-time reification of a floating, variable conceptual scheme which coordinates the production of beliefs within a culture. Other forms of practice, discursive or otherwise, are always "kicking back" against a given perspectival view, which survives just so long as it can withstand or absorb these challenges. This is particularly the case in "experimental" cultures such as scientific and, in the narrow sense exploited here, "ontological" ones—cultures whose *a priori* rather than by-product function is the very production of knowledge. A characteristic of such cultures is their own self-explication of the beliefs and practices they engage in—formalised in rule-governing theory and rule-governed methodology respectively. This characteristic ensures repeatable observations—a kind of perspectival continuity across time, space, and also other cultural boundaries. Perspectives also, critically, remain one-sided; from any point of view there is always another, perhaps infinitely many other points of view available, through other accultured lens. Aspects of objects are both seen and occluded under a given perspectival lens; belonging to a culture, no matter how highly self-reflexively critical, means sharing both its insights and its blindnesses (De Man, 1983).

Cultures, then, have conceptual schemes, or in Quine's other metaphor, a "web of beliefs". These beliefs can be described as structured like a network, spanning from the concrete, synthetic and empirical through to the abstract, analytic and conceptual—some beliefs are closer to the world than others. Again following Quine's breakdown of the synthetic/analytic divide, a belief can be plotted along a scale of *ontological/epistemological*: *ontological*—here in the philosophical sense—to the extent that it refers to objects in the world; or *epistemological*, to the extent that it refers to other beliefs (or their expression in language). A belief is canonically expressed in a proposition, an assertion of a relationship between concepts, objects and properties. Together beliefs are mutually supporting, forming in the ideal system a coherent, consistent and non-contradictory whole. Within the semi-bounded environment of a culture, contradictions may nevertheless emerge in discursive practice between agents. One of the roles of discourse is to establish the grounds upon which such intersubjective inconsistencies arise, to make assonance out of shared cognitive dissonance. Collectively, a network or web of beliefs constitutes a perspective—or, to use other common optical metaphors, an outlook, a point of view, a vantage point, or an orientation. A perspective, however, is not here a passive lens through which the world is viewed; rather it actively constitutes, constructs and intends—in the active, phenomenological sense of "intending"—how things are viewed and arranged. Actors partake or subscribe to belief networks to the extent they are imbricated in a culture, acquire its "habitus", although this is never (quite) a total imbrication. Through the roles they play and practices they enact, actors rather develop more or less intensive, comprehensive and enduring commitments to a set of beliefs. Understanding epistemic *extent*—the degree to which a belief is taken to be knowledge—is an important part of developing a profile of a culture.

Beliefs are transmitted in language, via what Habermas terms communicative practices. Communicative practice generally serves to break down what are otherwise incommensurable divides between cultures, and permit actors to participate in the "game of giving and asking for reasons", in Brandom's phrase. Hence assertoric utterances are paradigmatic instances of communicative practices—used to proclaim, query, test, revise, transmit, reconcile, and, in part, maintain cultural boundaries and integrity. Conveying of beliefs in language, while bearing the risk of a dissenting response, is above all an economic decision—it results in less work for belief transmission than other kinds of practices, of a presumably more coercive kind.

Beliefs form "webs" in a less benign Quinean and more insidiously Foucauldian sense—as socially norming practices, both discursive and otherwise. It might be possible in some cases to identify beliefs which are intrinsic and "core" to a culture—those which motivate practices and subsidise ancillary beliefs, and which constitute the non-negotiable intransigent elements of a cultural "perspective". These are likely to be those which are practically intractable to empirical or communicative challenge, since their invalidation threatens maintenance of the identity and boundaries of the prevailing culture. Belief revision is consequently largely a piece-meal affair, at least within the confines of a given culture, as the "carrying-out" of practices and even the revision of certain beliefs can only take place while the remainder of the belief system remains relatively stable. In this model, epistemic revolutions, as opposed to revisions, are rare.

Yet beliefs, as purely ideational and immaterial constructs, are essentially unknowable directly, and only can be inferred via the evidence of a culture's practices. For "ontological" cultures—those who produce explicit representations of some slice of the world they are concerned with—a conceptual scheme can be directly interpreted in highly regulated ways, via the semantic specifications embedded in those representations. Such explicit representations cannot, however, be interpreted, purely and unreservedly, as the accomplished perspective of the culture which produces them. Rather they are narrow, restricted and temporarily discrete frames on an ever-changing flux of objects—or, in another formulation, sense-data "perceivings" which only *a posteriori* congeal into the sorts of things conceptualisable as objects—subject to a continually changing dynamic process of theorisation and practice. Moreover they are also products with intended communicative effects. What is made explicit, then—the arrangement of concepts—needs interpreting not only in terms of its mode of explication, but against what remains tacit—a broader background of cultural beliefs and practices. Unlike the first kind of interpretation, operating directly on the axioms of a system itself and proceeding along set- or model-theoretic —in other words, strictly analytical—lines, the second kind is necessarily dependent upon exploratory, heuristic interpretive devices, using suggestive rather than direct forms of evidence. It is possible, then, to present knowledge systems generated by a culture as, instead of a stark unmediated delineation, a sort of highly detailed foreground, cast against a vague, impressionistic yet significant cultural backdrop. The resulting "portrait" of a culture is then comparable with other depictions—partly in the precise quantitative sense of two geometric conceptual graphs being compared isomorphically, but also in the deliberately imprecise sense of two holistic images being comparing impressionistically.

Picking up methodological cues from Gardenfors (2000), to generate a portrait involves analysing cultures across any number of possible dimensions, some of which might be especially salient within a particular translation situational context. Generically, cultures can be described in terms of a number of commonly occurring dimensions: size, rate of growth, "core" or foundational beliefs, practices, perspectives, material and environmental conditions, influence, aggressiveness, health, longevity, maturity, internal organisational structure, relation to other cultures, organisational type and purpose (economic, political, legal), and so on. Other, specific variables relating to the situation in which translation takes place can be used as well. One possible formalisation of generic variables is described in the set of dimensions outlined below. Regardless of exactly which set of variables are selected, and how they are respectively weighted for saliency, what matters at this stage is that it is possible to describe, qualitatively and quantitatively, both the explicit conceptualisations and tacit structures, beliefs and practices which underpin them, as a kind of portrait or profile. Commensurability of cultures involves, then, a comparison of the quantitative and qualitative profiles developed in this way. The "tacit" part of a profile is not, of course, truly silent—they represent aspects of a culture which need hermeneutic or heuristic interpretation, typically kinds of discursive, textual practices in which conceptual commitments need to be "drawn out" and inferred. Hence the methodological strictures, elaborated in Chapter 3 and repeated in a more applied context below, about what counts as evidence, and what limits apply to the inferences drawn from it—this form of interpretation is necessarily suggestive and exploratory, rather than definitive and explanatory.

5.2 Presenting a Framework for Commensurability

The above characterisation is sufficiently abstract to describe the vague kinds of entities which reside behind knowledge systems. The remainder of the chapter now makes a sharp transition from theory to practice; from a theoretical model to a framework which might help an analyst in working through practical problems of system translation. As indicated earlier, treatment of differences in knowledge systems takes place at least implicitly in several common information technology tasks—system integration, database design, information retrieval, decision support, resource planning, project management, and so on. A starting point for the framework is to describe what might be an idealised translation scenario, to serve as an approximation of the various real-world situations in which translation takes place. This provides a way of orienting the question of commensurability from the point of view of an analyst engaged in a translation process. The formalisation of the model also provides a way of moving from a qualitative to a quantitative characterisation of commensurability. From here, several generic dimensions for describing knowledge systems and their underlying cultures are proposed. Picking up on the more detailed discussion of method in Chapter 3, a schematic procedure for applying the dimensions is then discussed. The chapter is concluded with notes on the interpretation of the commensurability assessment.

It is worth briefly reviewing the motivations for the framework. Referring back to the introduction, there are broadly two ways of handling differences in knowledge systems. Computer science approaches focus on how to achieve individual concept alignment. They typically employ algorithms and external data definitions to match concepts from different systems. Matches can then be used to develop transformation rules to convert data from one system to another. These approaches can be broadly described as forms of semantic atomism—concepts are primary to the schemes containing them. Here by contrast system commensurability is considered in terms of plausible *schematic* alignment. This approach is fundamentally reliant upon an interrogation of the cultural character of these systems. Following one of Brandom's key distinctions Brandom (2000b), it can be considered a form of semantic *holism*, where the overall underlying cultural conceptual scheme is primary with respect to the individual concepts stipulated within it. Furthermore it can be described as predominantly interested in the pragmatic character of knowledge systems—what kinds of *use* they are put to. The difference in approach, then, is largely one of orientation and method; semantic holism as advocated here is consistent with algorithmic matching techniques described above, and it can be used as a supplementary heuristic to these techniques.

5.2.1 Modeling a Commensurability Scenario

Leading on from the preceding description, here a formal model of an idealised commensurability scenario or situation is presented. The scenario is idealised in that it may not correspond directly with the many actual contexts in which system translation, integration or alignment takes place, but it ought at any rate to capture key or exemplary features which enable the model to be generalisable to those contexts. The model distinguishes between knowledge systems and the "ontological cultures" responsible for authoring and using them. The model includes concepts explicitly defined by the system, as well those tacitly implied by it—background assumptions not evident in the system itself, but which can be inferred by the translating analyst. The model describes the differences between "cultures", in the sense defined above, against several dimensions. It assumes assessment of commensurability is for the purpose of aligning or harmonising two systems—or scoping out at any rate the work involved in such a task.

The model supports the idea of partial or gradual commensurability between systems. In the preceding chapter, the idea of "commensurability" was picked up from Kuhn's account of scientific paradigms—there, commensurability is represented in all-or-nothing terms. I suggested that at face value this goes too far, leading to forms of linguistic or cognitive relativism, and begging the question of how communication across cultural or paradigmatic divides could happen at all. Commensurability then becomes a reified, ontological property of the systems; not, instead—and more helpfully—an analytic tool for describing their translatability relative to a context. If commensurability is considered in comparative rather than mutually exclusive terms, however, the ontological character and associated critique drops away. By extension, discussion of fine-grained, more-or-less commensurable cultural conceptual schemes can dispense with the charge of relativism. "Local" schematic incommensurability, for example, can have reference to "global" commensurability, and a mutually untranslatable pair of systems might well be translatable when transplanted to another situational context, with new goals, additional information, different translators and so on. This also accords with everyday intuition—language users frequently agree to disagree about their use of individual concepts, for instance, while still sharing sufficient common ground for these localised disagreements to be understood.

The model assumes the following scenario:

1. There are two formal systems which need to be aligned or harmonised, *Sys1* and *Sys2*, which ought to meet the following conditions[1]:

    - They are based on some more or less explicit formal *language*, with appropriate syntax and semantics (candidates are the relational model, XML schema, RDF, OWL).
    - In terms of the *term-assertion* distinction—the systems in question must include a non-empty set of *terms* (or concepts), but not necessarily *assertions* (or objects / individuals).
    - The actual process of alignment or harmonisation is performed algorithmically, based on a series of transformational rules converting instances of concepts in *Sys1* to instances of concepts in *Sys2*. However, the details of this process are not relevant to the assessment of commensurability which precedes it.

[1] Additional systems need to be considered as multiple pairwise comparisons: three systems would involve three pairwise comparisons for instance. In general, where n is the number of systems, $\frac{n(n-1)}{2}$ is the number of pairwise comparisons needed.

2. There are two conceptual schemes, *Sch1* and *Sch2*, corresponding to the two formal systems. The schemes contain both explicit and tacit beliefs held by two "cultures", *Cult1* and *Cult2*, in the broad sense described above.

3. There is at least one designated purpose for the alignment or harmonisation. Collectively the set of purposes is defined as *P* (individual purposes could be designated using lower-case and prime notation, for example *p'*, *p"*, etc.).

4. The purpose(s) are established within a situational context, *Cxt*. Assessment of commensurability can be viewed as a judgement on the relative fit of cultures for a given purpose. The degree of applicability of the judgement is thus relative to the dynamics of the situational context. Making explicit the context in the determination of commensurability promotes reusability—subject to contextual qualifications—of the assessment. This may for instance be a simple statement of the environmental or situational conditions in which the alignment or harmonisation process takes place, or a more formal analysis [2].

5. There is some agent conducting the alignment or harmonisation, *Agt*. The agent is assumed to be a human individual or group, with appropriate techniques for characterising the formal systems.

6. Overall the alignment or harmonisation scenario consists of: two systems (*Sys1* and *Sys2*), developed and used by two cultures (*Cult1* and *Cult1*), a set of purposes (*P*), a context (*Cxt*), and an agent (*Agt*).

7. Commensurability, *Cms*, can be defined as the *degree of conceptual fit* between two cultures, *Cult1* and *Cult2*, responsible for the knowledge systems *Sys1* and *Sys2* respectively, given *P*, within *Cxt*, by *Agt*.

The model can be restated in plain language: assessing the commensurability for the "ontological cultures" responsible two formal knowledge systems, suitable to particular purpose(s) within a context, and to be conducted by an agent(s). The problem is further refined after the model of commensurability (*Cms*) is further elaborated below.

The model contains a series of *semantic dimensions* (following Gardenfors (2000)), which are applied to knowledge systems on the basis of interpretation of the cultures responsible for them. The model is therefore multi-faceted or multi-dimensional. Dimensions can be further characterised as follows:

- Dimensions (*Dim*'s) are salient properties of a "ontological culture"[3];
- Collectively the defined dimensions of the model form a set of dimensions (*DimSet*'s);

[2]SWOT and PESTLE analysis are examples of such formal contextual analyses.
[3]The word "property" itself is deliberately not used, to avoid ambiguity with properties defined within the systems themselves.

- Dimensions can be grouped at multiple levels, thus forming a tiered hierarchy;
- Dimension values are interpretations of aspects of a system and the culture responsible for it, relative to the purposes and other systems specified in the situational context;
- Interpretations are in the first instance qualitative; they can also be converted to quantitative measures to support statistical analysis. This entails assumptions about the dimensions and their application—a point further expanded on below.

Figure 5.1 shows the relationship between the major components of the model.

5.2.2 Quantifying Commensurability

The qualitative measures can be interpreted quantitatively, as ordinal measures. Here dimensions are represented as integer values between 0 and 10—any scale can be applied, so long as it is consistent across all dimensions in the dimension set.

Analysing commensurability then proceeds by assigning a value of 0 to 10 to each of the dimensions in the set for each of the systems being compared. This produces a set of values for both *Sys1* and *Sys2*, respectively *V1* and *V2*, corresponding to each dimension belonging to the dimension set *DimSet*. Commensurability between *Cult1* and *Cult2* is then derived from the collection of values *V1* and *V2* taken for *Sys1* and *Sys2*, as follows:

1. The difference between two dimension values for *Sys1* and *Sys2* are defined as the semantic *distance* (d) for the dimension in question.
2. Based on the collective purposes, P, and situational context, *Cxt*, the agent can assign a *weight, w,* against each of the dimensions. The weight is considered to be some value between 0 and 1. By default the weight is assumed to be 0.5 (permitting a relative strengthening or weakening of the weight). Weighting permits differential emphasis on dimensions of relevance or saliency to a given context [4].
3. Given n dimensions, three forms of commensurability measures can then be derived:
   (a) The average of the semantic distances. This is the sum of the differences between the dimension valuations, divided by the number of dimensions. It ignores the weightings. Its formulaic expression is:
   $\frac{\sum_{i=1}^{n} d_i}{n}$

[4] In a further refinement to the analysis, weights could also be applied against dimension groups. This could have the effect either of applying the weight to each of the dimensions within the group, or supplying a separate level of weighting. The first case is simply an overriding of the individual dimension weighting case; the implications of the second are not considered in detail here, but would have the effect of establishing multiple commensurability measures for different layers of the model.

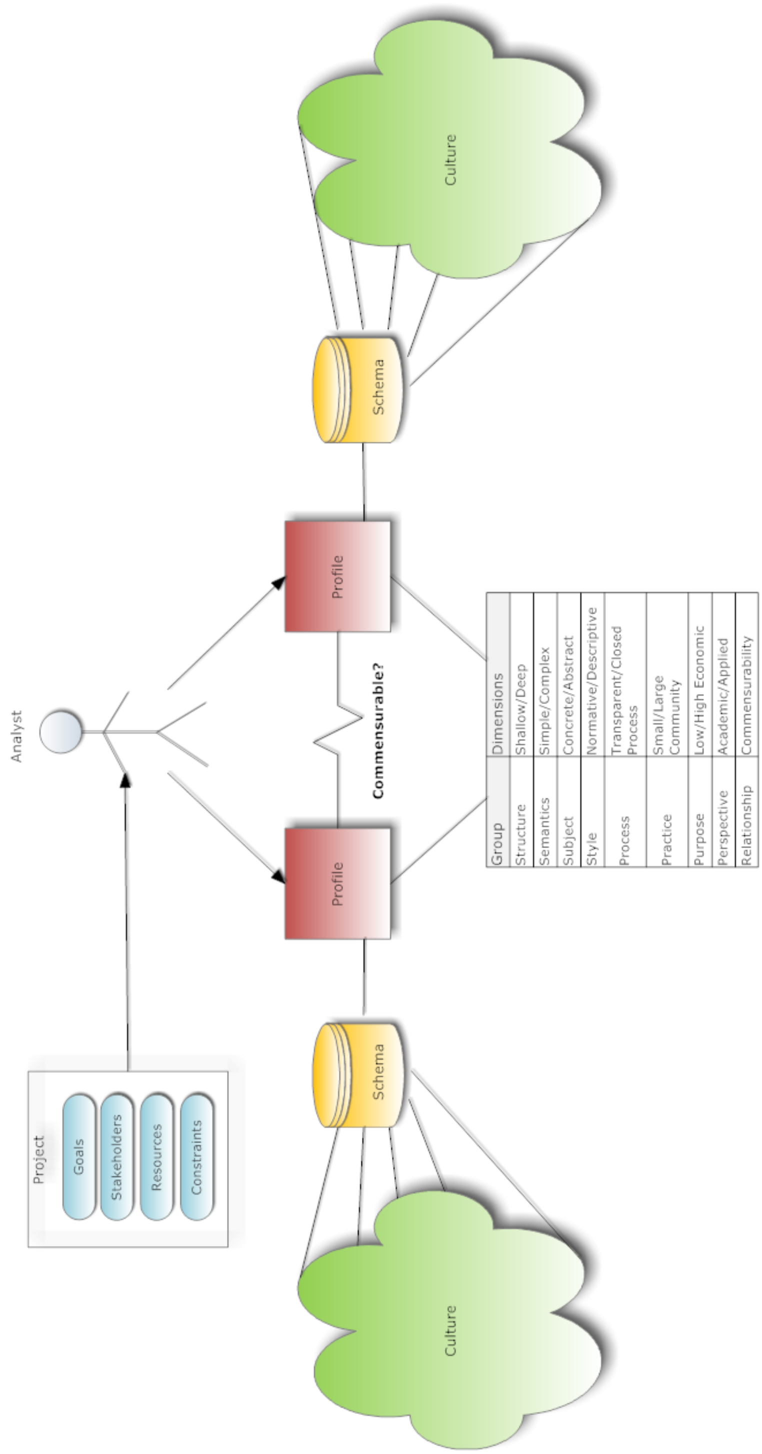

Figure 5.1: Commensurability Model

(b) The weighted average of the semantic distances. This is the sum of the weighted differences, divided by the sum of the weights. Its formulaic expression is:
$\frac{\sum_{i=1}^{n} d_i w_i}{\sum_{i=1}^{n} w_i}$

(c) The square root of weighted average of squared semantic distances. This is the sum of the weighted squared differences, divided by the sum of the weights, from which the root is calculated. This measure accentuates the weighting effect. Its formulaic expression is:
$\sqrt{\frac{\sum_{i=1}^{n} d_i w_i}{\sum_{i=1}^{n} w_i}}$

The second of these calculation, the weighted average, is the preferred formula for most purposes, since it is readily interpreted in relation to the unweighted average, but provides the benefit of differential assessment of dimension saliency. The derived value provides a quantifiable measure for the commensurability of the two cultural conceptual schemes, given the defined purpose(s) within a context, and as applied by the agent. The previous definition can now be restated more precisely:

1. Let *Sys1*, *Sys2* be two knowledge systems, and *Cult1* and *Cult2* be the cultures engaged with the respective systems.

2. An agent *Agt* is tasked with aligning or harmonising *Sys1* and *Sys2* in a given situational context (*Cxt*), for a set of stated purposes (P).

3. Let *Cms* be the unknown variable, the degree of conceptual fit or *commensurability* between *Cult1* and *Cult2*.

4. Then the calculation of commensurability, *Cms*, proceeds as follows:

   (a) Define some set of dimensions, *DimSet*, for describing conceptual schemes.

   (b) Interpret *Sys1*, *Sys2* against each of the dimensions, *Dim*, in the set *DimSet*.

   (c) Take the semantic distances, d, as the absolute difference between each of interpreted valuations.

   (d) Assign weights, w, against each of the dimensions, *Dim*, in the set *DimSet*, based on assessments of saliency of the dimension for the given purpose(s), P, within a context, *Cxt*.

   (e) Sum the weighted distances ($\sum wd$), and divide by the sum of the weights ($\sum w$).

   (f) The resulting weighted average provides a measure of commensurability, *Cms*, for the cultures *Cult1* and *Cult2*, underlying *Sys1* and *Sys2*.

This measurement can be used in turn as an estimate for assessing the complexity of aligning or harmonising the two knowledge systems. Some further remarks about how the measurement is interpreted and used are warranted at this stage:

- Dimensions tend to be descriptive, rather than judgmental. However, judgment is usually involved in the assignment of values to dimensions, hence the overall assessment should not be presumed to be value-free—rather, the point is that such value judgments are made explicit.
- In certain cases, applying a quantitative scale may imply a false degree of precision, and require greater rigour than the context warrants. In these cases, it might be sufficient to rate the systems as either "Low" or "High", or perhaps "Low", "Medium" or "High". In such cases, quantitative analysis can still be carried out by choosing appropriate values within the ranges set by dimensions with the greatest number of values. For example, if at least one dimension is scaled *[0, 10]*, then other dimensions must have appropriate values within the lower and upper bounds (i.e. between 0 and 10), and an equivalent mid-way value. Value ranges such as *[3, 7]* and *[2, 5, 8]*, for example, could be valid interpretations of the respective qualitative evaluations above.
- Dimension valuations can in some circumstances be added directly to the systems themselves. Most formal systems provide various metadata or annotation mechanisms. For instance, *OWL* provides annotation or metadata facilities which can be applied to the system as a whole, or to specific entities (classes or properties, for example) within it. Although the dimension valuations are related to a specific context, they may also be useful for future assessments of commensurability, or simply as annotated comments on the system itself.
- The set of dimensions constitute themselves a series of *ontological* claims about cultures and conceptual schemes. These claims are part, then, of a second-order conceptual scheme; the degree to which they require further explication and rationalisation will depend on context.

Contrasting Ontology Matching Approaches

As discussed earlier, recent work in schema and ontology alignment views that task as a "bottom-up" problem, that is, to be solved at the level of individual concepts (Shvaiko and Euzenat, 2008). Designers of matching algorithms employ various strategies for determining matches. They generally take the form of generating a set of matches based on:

1. A concept, *C1*, taken from *Sys1*;
2. A concept, *C2*, taken from *Sys2*;

3. A relation between concepts *C1* and *C2*: one of equivalence, generalisation, specialisation or disjointness;

4. A degree of confidence in the match.

It is clear why such approaches are semantically atomic, according to the terms outlined in this study. The degree of fit of the systems as a whole is derived from the completeness and precision of the set of matches obtained between individual concepts. Different strategies and algorithms can be compared with human interpretations in this regard. Nevertheless these approaches do not capture important contextual information about the knowledge systems, nor can they infer implicit information about the underlying cultural conceptual schemes. Rather this can only be inferred by a human agent who is capable of interpreting knowledge systems against a broader epistemological backdrop of purposes, contexts, and other social agents. Such interpretation is argued here as a form of semantic *holism*—in which specific conceptual representations can only be understood within a general social whole of meaning production and consumption.

Interpretation, of the kind required to describe dimensions of a conceptual scheme, is, however, a notoriously arbitrary process. As discussed previously in the methodology chapter, obvious criticisms are that interpretation is at best partial, subjective, and in some cases irrelevant or not feasible given a cost-benefit analysis or other justificatory measures. There are several possible responses to these criticisms of the framework: firstly, it supplements rather than competes with alignment algorithms—as such, it can be regarded as a form of human rather than computer-aided design tool; secondly, it is intended as a heuristic aid to alignment activities, not as a definitive prescription, for tasks not amenable to algorithmic analysis; thirdly, it merely formalises intuitions at work in everyday practice, albeit with a series of epistemological and methodological assumptions in tow; and finally, its inclusion of an appropriate set of dimensions and application of method serve to corral the worst excesses of interpretive work.

The dimensions presented in the next section endeavour to perform some of this corralling work.

5.2.3 Describing Commensurability—A Generic Dimension Set

The framework also includes a default generic set of dimensions for describing knowledge systems and the cultures behind them. In practice, as the case studies bear out, the default set often needs revision, extension and weighting to fit the requirements of a given translation situation. By abstracting out the formal model and process for quantifying commensurability, it is possible to use *any* suitable dimension set, without loss of general applicability.

Inevitably the choice of dimensions appears arbitrary, and need justification on grounds of saliency and relevance to the systems under consideration. The dimensions have been selected on the basis of utility for determining commensurability. Some of the intrinsic dimensions seem logical for any kind of system analysis; others—particularly those relating to context—are governed specifically by the account of commensurability presented here. The dimensions are intended to draw out *salient* differences in systems and their underlying cultures and conceptual schemes.

The set presented here itself is intentionally abstract, and aims to capture the general tendencies of the culture responsible for a knowledge system. The set distinguished between a) intrinsic and b) extrinsic dimensions of systems. The intrinsic dimensions reflect both the concepts, properties and individuals stipulated in the system itself, and its overall structural and stylistic features. Several of these have been extracted and simplified from schema and ontology metrics discussions mentioned in the literature review, notably in Tartir et al. (2005) and Yao et al. (2005). Unlike metrics, which can be computed just with reference to a single ontology, these dimensions are comparative—for example, the scope of a system can be judged to be general or specific only with reference to other systems under consideration.

The extrinsic dimensions aim to understand the implicit concepts which stand behind the system, which operate within the broader social environment in which the system is constructed. The distinction thus serves to differentiate a characterisation of the system itself from the characterisation of the environment in which it is constructed and used. A number of the extrinsic dimensions have been extracted or correlated to those developed in the standardisation and knowledge management literature discussed in Chapter 2. Others appear to be generic distinguishing traits differentiating knowledge systems, part of which has been bourn out in the case studies which follow.

Intrinsic Dimensions

Intrinsic dimensions describe the knowledge system itself. There are four types of intrinsic dimensions:

1. *Structure*—describes structural characteristics of the system; for example, whether the system is relatively large or small, or detailed or sparse.

2. *Style*—describes stylistic aspects of the system; for example, whether the system predominantly declares concepts or properties.

3. *Scope*—describes the scope of the system; for example, whether the concepts concentrated on a particular area, or dispersed over several.

4. *Subject*—describes the subject(s) dealt with by the system, and how these are characterised; for example, whether the concepts are relatively abstract or concrete.

Table 5.1 presents each of the dimensions with some brief explanation.

Table 5.1: Intrinsic Dimensions

Dimension Group	***Dimension***	***Description***
Structure		**Dimensions which describe the structural characteristics of the system.**
	Small—Large	Whether there are a small or large number of concepts in the system.
	Light—Dense	Whether the system contains a small or large number of properties and sub-classes for each class (this dimension corresponds to that of “Inheritance Richness” mentioned by Tartir et al. (2005), and of “Average Depth of Inheritance Tree of Leaf Nodes (ADIT-LN)” introduced by Yao et al. (2005)).
	Self-contained—Derivative	Whether the system uses only constructs defined internally, or makes use of imported constructs (can be determined by the presence of *owl:imports* declarations, and the extent to which imported constructs are used within the ontology).
	Free—Restricted	Whether the classes defined within the system have a small or large number of constraints applied to them (this dimension corresponds to that of “Relationship Richness” mentioned by Tartir et al. (2005)).
	Sparsely—Heavily Populated	Whether the system contains a small or large number of individuals.
Style		**Dimensions which describe the stylistic aspects of the system.**

Table 5.1: Intrinsic Dimensions

Dimension Group	***Dimension***	***Description***
	Classificatory—Attributive	Whether the system uses predominantly *sub-classes* or *properties/attributes* to describe relations between classes (this dimension corresponds to that of "Attribute Richness" mentioned by Tartir et al. (2005)).
	Literal—Object Composition	Whether the system uses predominantly data type literal or object type properties.
	Quantitative—Qualitative	Whether the system uses predominantly numeric or textual values for its data type properties.
	Poorly—Highly Annotated	Whether the system is well described (uses a high number of metadata annotations).
Scope		**Dimensions which describe the scope of the system.**
	Coherence—Dispersion	Whether the concepts listed in the system belong to an existing coherent system, or are seemingly "random" in their selection.
	Concentrated—Diffused	Whether the concepts are tightly clustered around a particular area or field, or are diffused over a range of fields.
	General—Specific	Whether the concepts are general in relation to a given field or fields; or are instead highly specific.
Subject		**Dimensions which describe features of the subject(s) dealt with by the system.**

Table 5.1: Intrinsic Dimensions

Dimension Group	***Dimension***	***Description***
	Concrete—Abstract	The degree the system relates to concrete objects (books, proteins, people) or tends towards abstract objects (space, time, substance). Ontologies are sometimes described as being "upper-level", "mid-level" or "low-level" according to their level of abstraction—this dimension describes the same feature.
	Natural—Social	Whether the system describes objects from a naturalistic or socialistic perspective (in philosophical terms, adoption of realist or constructivist perspective).
	Spatial—Temporal	Whether the system describes predominantly spatial objects (books, people, organisations) or temporal objects (events, periods, durations).
	Phenomenalist—Scientific	Whether the system describes objects from an everyday "phenomenalist" perspective, or from the standpoint of science.

Extrinsic Dimensions

Extrinsic dimensions describe the social context in which the system is developed. As with the intrinsic dimensions, there are four types of extrinsic dimensions:

1. Perspective—describes the stated intention or purpose of the system; for example, whether the system represents an ideal or a pragmatic conceptualisation of a field or domain.

2. Purpose—describes the underlying motivation (as best inferred) of the system; for example, whether strong financial or political motives underly the system's construction.

3. Process—describes the process of the system's design and construction; for example, whether the system design was relatively centralised or distributed.

4. Practice—describes how the system has been received; for example, whether the system is better characterised as a *de facto* or *de jure* standard.

Table 5.2 presents each of these dimensions.

Table 5.2: Extrinsic Dimensions

Dimension Group	***Dimension***	***Description***
Perspective		**Dimensions which describe the general perspective or orientation of the system.**
	Pragmatic—Idealistic	Whether the system is pragmatic—representing how concepts are presently represented in information systems—or idealist—suggesting how concepts ought to be represented.
	Academic—Applied	Whether the system is intended for academic research or for “real-world” applications.
	Serious—Spurious	Whether the system is intended for serious use.
	Speculative—Grounded	Whether the system is a speculative or hypothetical point of view about the objects it describes.
	Committed—Uncommitted	Whether the system is committed to the conceptual scheme it operationalises.
	Compatible—Independent	Whether the system is intended by design to be compatible with other systems.
Purpose		**Dimensions which the underlying motivations and purposes of the system.**
	Financially Motivated: Weak—Strong	Whether the system is motivated by financial considerations (for example, to promote related products and services, to cut costs of data management).

Table 5.2: Extrinsic Dimensions

Dimension Group	***Dimension***	***Description***
	Legally Motivated: Weak—Strong	Whether the system is motivated by legal considerations (for example, to support particular licensing arrangements, or to work around legal obstacles).
	Politically Motivated: Weak—Strong	Whether the system is motivated by political considerations (for example, to influence policy makers, or to form strategic alliances with organisations).
	Ethically Motivated: Weak—Strong	Whether the system is motivated by ethical considerations (for example, to promote interoperability among non-profit organisations).
	Personally Motivated: Weak—Strong	Whether the system is motivated by personal considerations (for example, to enhance individual career prospects).
	Theoretically Motivated: Weak—Strong	Whether the system is motivated by theoretical considerations (for example, to promote a given ontological orientation).
Process		**Dimensions which the process of the system's design and construction.**
	Representative—Unrepresentative of Community	Whether the system is representative of the community who makes use of it.
	Central—Distributed Design	Whether the system is designed by a central body or via a distributed community.
	Closed—Transparent Process	Whether the system is designed in a way which elicits and incorporates critical review and feedback.

Table 5.2: Extrinsic Dimensions

Dimension Group	***Dimension***	***Description***
	Formal—Informal Construction	Whether the system uses a formal process, such as those used by international standards bodies.
	Explicit—Implicit Assumptions	Whether the system makes explicit background assumptions, as understood by those involved in its design.
	Rigorous—Random Method	Whether the system makes use of a rigorous method in its design.
Practice		**Dimensions which describe how the system is used.**
	Active—Inactive Community	Whether the system is designed and/or used by an active community.
	Low—High Adoption Rate	Whether the system has a high adoption rate among its candidate users or market.
	Low—High Maturity	Whether the system is mature—has gone through multiple iterative cycles or version.
	Backward Compatible—Incompatible	Whether the system is compatible with earlier versions of the system.
	De Facto Standard: Low—High	Whether the system is a *de facto* standard among its users.
	De Jure Standard: Low—High	Whether the system is a *de jure* standard—has received ratification from appropriate standards bodies.
	Industry Support: Low—High	Whether the system is widely supported within the industry (as evidenced by supporting documentation, tools, services, etc.) .
	Documentation Availability: Low—High	Whether the system is supported by available documentation.

Preempting the methods discussion below, the extrinsic dimensions clearly require considerable interpretation. In contrast, some of the intrinsic dimension values may be derived algorithmically, especially in the case of the structural and stylistic dimensions. It is also clear that accurate evaluation of extrinsic dimensions may require considerable discovery effort. The extent of effort needs to be justified against the benefit of the assessment, on the basis of some kind of cost-benefit analysis. Nevertheless evaluation itself can be more or less formal or extensive—for certain purposes and contexts, existing knowledge or opinion may be sufficient, or the dimensions introduced here can be applied in an *ad hoc* fashion.

In conjunction the intrinsic and extrinsic dimensions provide a characterisation of the knowledge systems in terms of both their underlying conceptual scheme, and the background cultures responsible for them. The intrinsic *Subject* and extrinsic *Intention* dimension groups do most to capture the implicit elements of the conceptual scheme; while the other intrinsic groups summarise what is already explicit but not immediately conveyed in the system; and the other extrinsic groups contextualise the system in ways that make more evident the causes behind the construction of the system itself. The next section outlines how the model can be applied in a given commensurability assessment scenario.

5.2.4 Assessing Commensurability—Applying the Dimensions

As a final part of the overall framework, a basic procedure is proposed for the application of the dimensions to the systems. The method of construction can be minimal or highly sophisticated, depending upon the context of the assessment. Nevertheless, some explicit treatment of method, in terms of how the model might be applied, is useful. The method assumes the idealised scenario presented in the discussion of the analytic procedure above—namely, *Sys1*, *Sys2* represent the two systems, *Cult2*, *Cult2* the underlying cultural schemes, *P* the purpose(s), *Cxt* the context, and *Agt*, the agent.

Firstly, the intrinsic character of *Sys1* and *Sys2* are described. This involves:

1. Surveying of parts or all of the definition of *Sys1* and *Sys2* . The "definition" may be precisely specified in a formal language, or need to be inferred from secondary documentation. The following is a list of potential sources for analysing the definition:

   - The source definition of the system: the concepts and properties declared in XML Schema files, RDF/OWL ontologies or relational models;
   - System documentation, which may be in the form of annotations to the source definition, external documentation or academic publications;
   - Diagrammatic representations of the system, such as entity relational (E/R) or Unified Modeling Language (UML) diagrams;

- Available metrics summarising structural or stylistic aspects of the system;
- Secondary sources analysing or discussing the systems.

2. Analysis and rating of the systems according to the intrinsic dimension groups of *structure*, *style*, *subject* and *scope*. In the case of structural and stylistic dimensions, it may be useful to employ algorithms for counting numbers of concepts, properties, annotations, restrictions and individuals. The following list are examples of how the given intrinsic dimension groups and dimensions might be analysed:

   - *Structural* dimensions—may involve counting the number of concepts and properties; finding "import" declarations; and checking the extent of constraints applied to concepts and properties.
   - *Stylistic* dimensions—may involve counting the relative number of concept and property declarations; examining property types (whether they are literal or relations); examining literal property types (whether they are numerical, textual or other); checking the internal documentation (whether the system entities are annotated); and examining whether there are multiple methods to describe an object.
   - *Scope* dimensions—may involve interpreting whether the concepts are coherently grouped or seemingly random; concentrated around their subject matter, or diffused; and general or specific.
   - *Subject* dimensions—may involve interpreting whether concepts are concrete or abstract; temporal or spatially-oriented; and refer to natural occurring or socially constructed objects.

3. The valuations and differences between the intrinsic properties of the system can at this point be analysed by grouping averages by dimension group.

Secondly, the extrinsic dimensions of the systems are analysed. This in turn involves:

1. Surveying the social environment in which *Sys1* and *Sys2* are developed. Depending upon the scale of the method, availability of sources and nature of the systems, this could incorporate several different methods:

   - Interviews with the system designers and with other users of the system.
   - Affiliation or participation in working groups, standards committees and design teams.
   - Analysis of online social groups—blogs, wikis, forums, mailing lists—in which aspects of the system design are discussed or negotiated.
   - Review of secondary materials: press, academic publications, conferences, journals and books which discuss aspects of the systems.

- Review of peripheral materials: government policies, company financial reports, industry group minutes, standard body procedures related to organisations sponsoring, advocating or using the systems.

2. Analysis and rating of the systems according to the extrinsic dimensions. This requires interpreting the materials in terms of the dimension groups of perspective, purpose, process and practice. The following list are examples of how the given extrinsic dimension groups and dimensions might be analysed:

   - *Purpose* dimensions—may involve examining the stated and implied intentions behind a system, including any economic, political, philosophical or technical rationales evident in the context of the presentation of the systems themselves (websites, accompanying documentation) and other sources (forums, commentaries, and so on).
   - *Process* dimensions—may involve looking at how the system is developed: what explicit or implied policies determine how the system is designed, versioned, ratified and publicised.
   - *Practice* dimensions—may involve examining how the system is used within different environments; whether it is widely endorsed, supported and integrated within an ecosystem of other systems, standards and products.
   - *Perspective* dimensions—may involve direct interpretation or indirect sourcing of commentary about the general "orientation" of the system: whether it is oriented towards everyday "lay", or scientific vocabularies; whether it adopts a realist or constructivist position towards the objects it describes; or whether it uses existing vocabularies or enforced a new normative vocabulary of its own.

3. The valuations and differences between the extrinsic properties of the system can also be separately analysed quantitatively, to generate averages by dimension group.

Finally, the weighted average of all of the dimensional differences is obtained to provide a quantitative measure of commensurability, using the procedure outlined above. Any qualitative remarks, against dimensions or dimension groups, can also be summarised into an overall qualitative assessment.

5.2.5 Interpreting Commensurability Assessments

Both qualitative and quantitative assessments need to be interpreted relative to the specific context in which the assessments have taken place. This is particularly the case for the quantitative measurement. High values of commensurability should correlate to quicker and less problematic alignments between the systems concerns; conversely, low values should indicate slower and more difficult alignments. Low values might also suggest the need for various further activities: further consultation with those knowledgeable about the respective systems; iterative cycles of translation; more rigorous testing procedures; or, finally, that the task of translation is not viable within available constraints. In some situations, these determinations might have other, flow-on effects and impacts: the desirability for one system over another, for example, or even of the "strategic fit" between two organisational cultures. Just as the background cultures responsible for two systems impacts upon their relative commensurability, the "embeddedness" of systems means their compatibility can be an indicator and even determinant for general questions of cultural alignment and affiliation. These, naturally, need to be asked with reference to specific operating conditions; so here no more than a vague indication can be provided for what commensurability assessments might mean, and how they ought to be interpreted, within those conditions. Some of these considerations are, however, presented below in itemised form, to prompt this interpretative process:

- What does a high value, signalling a high degree of *in*commensurability, indicate? What if any consequences does this have?

  Does it mean that the systems are *radically* incommensurable, and any effort to align them will be in vain? Or does it entail practical consequences: a greater amount of work is required, additional resources or time need to be allocated, or further analysis or different approaches need to be explored? Or does it indicate a preferential choice of one system over another, where the dimensions have been interpreted as selection criteria?

  Conversely, what does a low value signify? That the systems are commensurable for the stated purposes, or that alignment or harmonisation of the systems is comparatively trivial?

- How do the quantitative and qualitative assessments compare? Are they consistent, and if not why not? Do some of the dimensions perhaps need to be re-weighted?

- How do the assessments fit with intuitive understandings of the general "fit", or commensurability, of the systems concerned?

- What other steps or stages—consultation, testing, the alignment itself—need to be modified as a result of the assessments? Qualitative as well as quantitative findings could prompt particular decisions here.

- What follow-up actions or decisions might eventuate from these assessments? Do they indicate preference for one system over another? Are there alternate ways of achieving the ends to which the system alignment or translation is directed?

- Are there broader implications of these assessments? Do they reflect important "extra-systemic" features, such as the "strategic fit" between organisations or organisational units?

5.3 Applying the Framework

This chapter ties together the strands of the first half of the study, which outlined the research questions, pertinent insights from the literature, the methodology and some of the theoretical backdrop to the question of commensurability of formal knowledge systems. Against this background, the chapter proceeds to develop a general theoretical rubric and detailed framework for assessing the commensurability of both formal systems and the cultures responsible for them. The framework has four components: a model of an idealised commensurability scenario, a series of dimensions conforming to the demands of the procedure, a means for quantifying commensurability and a method for applying the framework and interpreting the results. The framework is the fulcrum around which the response of the study to the central research question pivots: that the commensurability of knowledge systems can be explored through a holistic interrogation of both the systems and the cultures responsible for them. The framework mobiles a series of analytic tools for understanding both the explicit and implicit commitments entailed by those systems—both those directly stipulated in the systems themselves, and those inferred through an examination of the background cultures in which they are produced and used. The series of dimensions uses the distinction between intrinsic and extrinsic dimensions to capture each of these types of commitments. The separation of the model and methodology permits the adoption of entirely different dimensions, allowing for considerable flexibility in how other criteria and even different ontological and epistemological assumptions come into play in the analysis.

The following three chapters apply the framework in an exploratory fashion, in part to evaluate its effectiveness, and in part to examine real world cases where the question of commensurability genuinely arises. Chapter 6 compares two knowledge system types—the relational database and Semantic Web ontologies—against the historical context of the rise of logic and knowledge systems in the twentieth century. Chapter 7 examines recent efforts to construct "upper-level" ontologies, conducted in the relative pristine surrounds of academia. Chapter 8 then looks at the controversy over document format standardisation, which moves into the murky grounds of government policy and corporate product positioning. Chapter 9 engages other users in an artificially constructed commensurability problem, using a pared down form of framework for practical purposes. In the process the framework itself is road-tested upon the rocky terrain of empirical case studies and exercises. The conclusion seeks to survey how the framework fared in the process, and looks at recommendations for improvement and further work.

Chapter 6

Case Study: Formal Knowledge Systems

> Kant moreover considers logic, that is, the aggregate of definitions and propositions which ordinarily passes for logic, to be fortunate in having attained so early to completion before the other sciences; since Aristotle, it has not lost any ground, but neither has it gained any, the latter because to all appearances it seems to be finished and complete. Now if logic has not undergone any change since Aristotle—and in fact, judging by modern compendiums of logic the changes frequently consist mainly in omissions—then surely the conclusion which should be drawn is that it is all the more in need of a total reconstruction; for spirit, after its labours over two thousand years, must have attained to a higher consciousness about its thinking and about its own pure, essential nature . . .
>
> Regarding this content, the reason why logic is so dull and spiritless has already been given above. Its determinations are accepted in their unmoved fixity and are brought only into external relation with each other. In judgments and syllogisms the operations are in the main reduced to and founded on the quantitative aspect of the determinations; consequently everything rests on an external difference, on mere comparison and becomes a completely analytical procedure and mechanical calculation. The deduction of the so-called rules and laws, chiefly of inference, is not much better than a manipulation of rods of unequal length in order to sort and group them according to size—than a childish game of fitting together the pieces of a coloured picture puzzle (Hegel, 2004, p. 51).

Analysts discussing knowledge systems typically distinguish their *logical* (or procedural) and *ontological* (or data) components (Smith, 1998; Sowa, 2000). To employ another related distinction, the logical part can be termed the *formal* component of a system—what preserves truth in inferential reasoning—while the ontological part can be considered the *material* component—or what is reasoned about. While the case studies which follow in subsequent chapters focus explicitly on the variant cultural conceptual schemes behind systems expressed in the *same* logical formalism, the present case study looks at the minimal ontological assumptions which reside in two *different* kinds of systems—the logical formalisms employed, respectively, in relational databases and Semantic Web ontologies. As well as providing an important example of how commensurability can be assessed for the formal apparatuses by which knowledge systems are constructed, then, this study also provides useful historical context for the more narrowly scoped studies which follow. Moreover, it demonstrates that even the austere and minimal constructs employed by these formalisms cannot avoid importing ontological concerns.

This chapter develops a general historical narrative, which plots the development of knowledge systems against three successive different waves of modernisation. This development is inherently tied to the rise of symbolic logic in the modern era, without which both computation generally, and knowledge systems specifically, would not be possible. A constant guiding goal, which can be termed, following Foucault, the pursuit of a "mathesis universalis" (Foucault, 1970), motivates this development. At its most extreme, this goal represents a form of epistemological idealism; it imagines that all knowledge can be reduced to an appropriate vocabulary and limited rules of grammar and inference—in short, reduced to a *logical system*. The extent of this idealism is itself an important feature of the different formalisms surveyed. To focus on this and other significant points of difference and similarity, the characterisation of the history of this development is intentionally schematic; it does not attempt a broad description of the history of logic, computers or information systems.

The study does however aim to illustrate the rough affinity between the specific history of knowledge systems and the much broader history of modern industrialisation and capitalism. This is in part to counter the tendency of histories of logic and computing to present them as purely intellectual traditions, with only coincidental application to problems of industry, bureaucracy and governance. Logical "idealism" in fact arose specifically in those places and times which demonstrated a practical need for it—because, in a sense, both the quality and quantity demands of organisational knowledge management, traceable back to the rise of the bureaucracy in the nineteenth century, foreshadowed the emergence of information systems concurrently with the greater waves of modernity in the twentieth. The conclusion of the chapter suggests that the nexus of tensions which arise in modernity play a structuring role in the production of incommensurability.

The structure employed here distinguishes between "pre-modern", "modern" and "postmodern" development phases of knowledge systems. The "pre-modern" and "modern" periods cover, respectively, the scattered precursors and the more structured programs in logic and mathematics which pointed towards the development of knowledge systems. Early knowledge systems, such as the relational database, can be said to apply the results of "modernist" logic in the form of highly controlled structures of knowledge. "Post-modern" knowledge systems, on the other hand, arise out of the perceived difficulties of coercing all forms of knowledge into rigid structures. In particular, the era of the web has inspired the construction hybrid, semi-structured knowledge systems such as Semantic Web ontologies—combining some of the computational properties of relational databases with support for documents, multimedia, social networks and other less structured forms of data and information.

The latter part of the chapter shifts from an historical overview towards a more detailed examination of the question of commensurability of relational database and Semantic Web systems. In particular it looks at one stark area of potential incommensurability—that of so-called "closed" versus "open" world assumptions. While this area of incommensurability is well documented within the relevant literature (Reiter, 1987; Sowa, 2000), it resonates with several broader cultural distinctions between the two kinds of systems. These distinctions, along with several recent discussions of them, are then reviewed, followed by a suggestive assessment of commensurability between the two kinds of knowledge representation surveyed.

The conclusion of the chapter recasts knowledge systems back into a broad historical frame, suggesting several causal factors behind the production of differences between them. These suggestive indications are further developed in the more detailed case studies of subsequent chapters.

6.1 Pre-Modernity: Logical Lineages

Retrospectively, it appears that modern knowledge systems are the culmination of a steady linear development in the field of logic. In the past century and a half, since Frege's efforts to systematise logic in symbolic form, progressive and continuous advancement is a plausible narrative line. Prior to Frege, however, logic appears at relatively brief intervals in the development of Western thought. A more fitting metaphor is perhaps that of an expanding series of fractal-like spirals—sporadic and incidental surges during the ancient, medieval and Enlightenment periods, prior to a sudden and sustained preoccupation from the nineteenth century onwards (Kneale, 1984). Indeed, as the quote from Hegel suggests, at the start of the nineteenth century, logic was perceived to be a field for the most part exhausted by Aristotle's exposition of syllogisms. More recent histories have shown a somewhat more complex picture: important precedents to modern logic variants, such as predicate, modal and temporal logics, can be found in Aristotelian and later classical works on logic (Bochenski, 1961), as well as in medieval scholasticism (Kneale, 1984).

Notwithstanding these precursors, it is generally agreed that not until the seventeenth century was something like contemporary symbolic predicate logic, upon which knowledge systems are based, conceived (Kneale, 1984; Bochenski, 1961). Largely the product of a solitary figure, Leibniz, this conception was of a universal symbolism—*universalis mathesis* (Foucault, 1970)—which would provide both a standardised vocabulary and formal deductive system for resolving disputes with clinical and unambiguous clarity (Davis, 2001). Leibniz dreamed of a process which could strip all argument from the vagaries and ambiguities of natural language, leaving only a pristine set of statements and rules of valid inference in its place:

> If this is done, whenever controversies arise, there will be no more need for arguing among two philosophers than among two mathematicians. For it will suffice to take pens into the hand and to sit down by the abacus, saying to each other (and if they wish also to a friend called for help): *Let us calculate*! (Lenzen, 2004, p. 1)

Set in the context of Cartesian geometry, Newtonian physics, Copernican cosmology, the construction of the calculus, and a host of other mechanical formalisations of the seventeenth century, that mathematics should be seen to be the epistemological pinnacle towards which other kinds of thought might aspire—to reason "clearly and distinctly", as another rationalist, Descartes, put it—is perhaps not surprising. At the time, consensual workings-out of "controversies"—with or without the aid of a "friend"—was an important intellectual concomitant to the preferences for personal introspection over traditional, largely clerical authority, for rationality over dogma, for individual decision-making over ecclesiastical mandate, and for mechanical laws over divine decrees, all of which mark the emergence of the Enlightenment (Habermas, 1989). The cry to resolve disputes via "sitting down by the abacus"—or any of its contemporary analogues—was, however, to inspire a much longer and sustained wave of rationalist oneirism only by the middle of the nineteenth century. Arguably, Leibniz' fervour was not yet met by a sufficiently developed and broader need for rationalised and standardised communication in the social sphere at large. From the nineteenth century onwards though, three further distinct points can be isolated within this historical trajectory: Frege's repudiation of German idealism and psychologism in the late nineteenth century, which paved the way for symbolic logic; logical positivism's rejection of metaphysics, and its search for a purified, foundational mathematics; and, most importantly, subsequent post-war exploration of computational methods to represent, refine and extend human knowledge, which gradually filtered down from "pure" research to applied problem-solving in a myriad of practical contexts. What began as an individual exhortation, barely a rippling murmur in a sea of philosophical discourse, had, by the twentieth century, coalesced into a tradition of what Rorty (1992) termed "Ideal Language Philosophy"—a putative, therapeutic program for extending the use of language, ultimately, from the selective company of human agents to that which would embrace a wider family of computational agents as well.

One of the foundational populist expressions of the ambitions of the Semantic Web, published in the Scientific American in 2001, gives a modern rendering of this zeal for intellectual asceticism:

> The Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling

> computers and people to work in cooperation. The first steps in weaving the Semantic Web into the structure of the existing Web are already under way. In the near future, these developments will usher in significant new functionality as machines become much better able to process and "understand" the data that they merely display at present ...
>
> The Semantic Web, in naming every concept simply by a URI (*Uniform Resource Identifier*), lets anyone express new concepts that they invent with minimal effort. Its unifying logical language will enable these concepts to be progressively linked into a universal Web. This structure will open up the knowledge and workings of humankind to meaningful analysis by software agents, providing a new class of tools by which we can live, work and learn together (Berners-Lee et al., 2001).

As with the Enlightenment, these more recent moments have been accompanied by broader ideological trends. These are sketched out in more detail below—in part to emphasise the inter-dependent structural connections between the emergence of knowledge systems, on the one hand, and the rise of distinct styles of modern organisation and management—features of contemporary capitalism—on the other; and in part to help explain how variant knowledge formalisms—even at a level of abstraction from questions of conceptual content—still bear substantial epistemological assumptions. These assumptions, in turn, can have significant bearing on how systems based on these formalisms might be considered commensurable.

6.2 Early Modernity: the Mechanisation of Thought

After Leibniz, the dream of a formal mechanism for "calculating" the logical outcome from a set of premises was to remain dormant for a considerable period. Variants of Germanic idealism sought instead to emphasise the irreducibility of thought to pure procedure. Even the ostensibly logical works of Kant and Hegel differentiated the sphere of the rational from other modes of thought: practical/ethical and judgment/aesthetic categories were *procedurally*, not just substantively, differentiated. Foucault goes so far as to argue that the eighteenth and early nineteenth centuries, in the human sciences at least, are marked by a departure, at the level of method, from attempts at a common, universal and formal language:

> In this sense, the appearance of man and the constitution of the human sciences ... would be correlated to a sort of 'de-mathematicization' ... for do not the first great advances of mathematical physics, the first massive utilizations of the calculation of probabilities, date from the time when the attempt at an immediate constitution of a general science of non-quantifiable orders was abandoned? (Foucault, 1970, p. 349–50)

It was not until the mid-nineteenth century, coincidentally when industrialisation, and the associated widespread mechanisation of industry, grew rapidly (Hobsbawm, 1975), that logic began again to take on importance as an active field for new research in its own right. The incipient form of logic as a coherent and regulated, machine-like system began to take shape in four related British works around the middle of the nineteenth century: Richard Whately's *Elements of Logic (1826)*; William Thomson's *Outlines of the Laws of Thought* (1842); John Stuart Mill's *A System of Logic* (1843) and, most significantly, George Boole's *An Investigation of the Laws of Thought* (1854). These developments, contemporaneous with the early computational designs of Babbage, mark a shift in the treatment of logic from a study of modes of argumentation (as a sibling discipline to rhetoric) to a study of a *system*, with strong affinities to mathematics—logic begins here to be considered as a kind of *calculus*, of the kind Leibniz envisioned, rather than a mere rhetorical aid (O'Regan, 2008). This is especially evident in Boole's landmark text, which not only marks its discussion of logic with algebraic rather than verbal terms, but introduces for the first time a set of logical operations equivalent to those of arithmetic (logical product, sum and difference) (Bochenski, 1961; Kneale, 1984). Evidence of the radical nature of this effort is indicated by a prolonged defence in the introduction:

> Whence it is that the ultimate laws of Logic are mathematical in their form; why they are, except in a single point, identical with the general laws of Number; and why in that particular point they differ;—are questions upon which it might not be very remote from presumption to endeavour to pronounce a positive judgment. Probably they lie beyond the reach of our limited faculties. It may, perhaps, be permitted to the mind to attain a knowledge of the laws to which it is itself subject, without its being also given to it to understand their ground and origin, or even, except in a very limited degree, to comprehend their fitness for their end, as compared with other and conceivable systems of law. Such knowledge is, indeed, unnecessary for the ends of science, which properly concerns itself with what is, and seeks not for grounds of preference or reasons of appointment. These considerations furnish a sufficient answer to all protests against the exhibition of Logic in the form of a Calculus. It is not because we choose to assign to it such a mode of manifestation, but because the ultimate laws of thought render that mode possible, and prescribe its character, and forbid, as it would seem, the perfect manifestation of the science in any other form, that such a mode demands adoption (Boole, 2007, p. 11).

For Boole, rendering the laws of thought "in the form of a Calculus" becomes "perfect manifestation of the science", and a natural accompaniment to the greater scientific enterprise then burgeoning in mid-nineteenth century Britain. It is an undertaking which, moreover, fits comfortably with the broader economic and military aspiration of a global-looking empire (Hobsbawm, 1975). Nevertheless, as the titles of these works indicate, logic remained a description of concomitant mentalistic "laws of thought"—however much they may be "mathematical in their form" (Boole, 2007). That these laws themselves belonged to the domain of mathematics, or perhaps might found a new branch of "metamathmatics", rather than psychology—and thus could be replicated by a machine—was an implication yet to be developed. For Frege, writing a little later in the nineteenth century, expressions such as "laws of thought" were the last vestiges of a discipline about to be wrenched from its psychologistic origins (Kneale, 1984). Subsequently, logic was to re-oriented onto new disciplinary foundations, not on the basis of a mere analogy or affinity with mathematics, but as no less than the very *foundations* of the mathematical enterprise.

The latter half of the nineteenth century witnessed the emergence of two new global powers which could compete with the military, economic and technological dominance of the British Empire—Germany and the United States (Hobsbawm, 1987). Coincidentally these two countries also boast the two seminal logicians of this period, in Frege and Peirce. Quite independently, and in the case of Peirce, to relatively little initial acclaim, they worked to develop completely axiomatised logical systems, which in turn would form the basis for all modern-day formal knowledge systems (Sowa, 2000; Davis, 2001). Frege, in particular, developed three pivotal and influential innovations: the "concept script" (*Begriffschrift*), a notational language of symbols with variables and constants with well-defined semantics; the vital conceptual distinction between connotational meaning (sense—*Sinn*) and denotational meaning (reference—*Bedeutung*); and, most notably, the formalisation of quantified predicate logic, which as one historian suggests "was one of the greatest intellectual inventions of the nineteenth century" (Kneale, 1984). While Frege's notation was never widely adopted, and presented considerable intellectual challenges to its early readers, the recognised flexibility of predicate logic allowed for a explosion of interest in "metamathematical" problems—how to develop a foundational system from which all of mathematics could be derived (van Heijenoort, 1967). Together with Cantor's set theory, at the turn of the twentieth century, it now appeared at least possible to unite mathematics under a single universal theory—indeed, the very desire to develop, for the first time, a unified coherent theory itself points to an uniquely modern epistemology of mathematics (Davis, 2001). More ambitiously still, the challenge of erecting *all* knowledge upon the rigorous epistemological foundations of logic and mathematics could now be conceived—a challenge which, around the turn of the century, was indeed posed by the mathematician Hilbert, and soon after, was also accepted by Whitehead and Russell (van Heijenoort, 1967).

6.3 Crises in Modernity: the Order of Logic and the Chaos of History

The fascination with propositional *form* which characterises the enthusiasm for symbolic logic in the early twentieth century has its suggestive cultural analogues in the geometric obsessions of cubism, the calculating devices of the new mass culture industries, modernist architecture, the ordered urban planning environments of Le Corbusier, and the shared desire and horror of order that is a continued motif of modernist art and literature (Adorno, 2001; Hobsbawm, 1994). It is also parallels the development and interest in a host of more mundane technologies—double-entry book-keeping, time-and-motion studies, efficient transportation, assembly-line manufacturing, punch-card tabulation, the growth of explicit management techniques, to mention but a few (Hobsbawm, 1994). The first half of the twentieth century saw a highly productive period in the formalisation of logic, and laid the foundations for contemporary research in artificial intelligence, cognitive science and a host of affiliated disciplines today. It is during this period, too, that the latent potentials of logic began to coalesce with a fully-fledged modernity to provide the kinds of technological instrumentation required to meet the demands of large-scale administrations and bureaucracies. Here the quantitative growth of organisational data collated would outstrip the capacities of pre-digital storage technologies—and companies quickly emerged to fill the breach: the late nineteenth century already witnessed the growth of one corporate entity willing to service government census needs with new tabulating machines, which by 1915 had, after a three-way merger, started to operate under the now familiar name of *International Business Machines* (IBM Corporation, 2009). Yet formal logical systems were, by and large, still considered without direct regard for their applications. Prior to the elaboration of the first computers during and after the Second World War, the steady production of theorems in set theory, model theory, foundational arithmetic and mathematical logic form the basis from which something like modern information and knowledge systems could emerge.

These innovations happen within an era of unprecedented political and economic crisis: two world wars, numerous political revolutions and the Great Depression (Hobsbawm, 1994). The surrounding turmoil of Europe often appears eclipsed in the isolated intellectual histories of this period, which feature predominantly the relative sanctuaries of Cambridge, Oxford, Vienna, Warsaw universities, and eventually those of Berkeley, Harvard and Princeton too. Yet the application of logic in military, administrative and organisational context was to become an important factor in funding and direction of problem solving within these as yet relatively small academic circles (Ceruzzi, 2003). Some of the key figures in the emergence of the information age—Turing and von Neumann—made vital contributions, respectively, in code breaking and the construction of the atomic bomb (O'Regan, 2008). Notoriously, the Nazis utilised ever more efficient information systems for cataloguing concentration camp prisoners—recently, for instance, it has been claimed that this use of punch-card tabulators involved lucrative agreements and ongoing business with IBM subsidiaries (Black, 2002). But on a more general level, systems for tabulating and calculating at high speeds for academic, governmental, commercial or military purposes meant that there was significant curiosity about the otherwise arcane results emerging from this form of theoretical enterprise, even if it did not hold the public attention in the way that, for example, theoretical physics did from the First World War onwards.

The following sections outline some of the salient developmental steps in the construction of both computers generally and knowledge systems in particular.

1910s—Mathematical Principles

In *Principia Mathematica*, Whitehead and Russell (1910) endeavoured to re-found the entirety of mathematics on the new "meta-mathematics" of formal logic. This work developed upon Frege's system, and was to prove instrumental in inspiring the development of the austere brand of philosophy by the Vienna circle in the 1920s, known as logical positivism (van Heijenoort, 1967). *Principia Mathematica*, more than any other work, was responsible for directing Anglo-American philosophy away from metaphysics, idealism and the naïve empiricism of the nineteenth century, and towards an empiricism instead founded upon the precise use of a language resolutely committed to describing facts—a language epitomised in the severe codes of symbolic logic. The impetus behind Russell and Whitehead's project remained that of Leibniz' dream, but phrased now in tones less of wishful thinking and more of matter-of-factual inevitability. The task of logical analysis, in Russell's telling introduction to Wittgenstein's work, is to show "how traditional philosophy and traditional solutions arise out of ignorance of the principles of Symbolism and out of misuse of language" (Wittgenstein, 1921). At the heart of this vision, in a reductionist form, is the idea that, once the appropriate logical vocabulary is supplied, and the concepts of a field made sufficiently clear, all knowledge can be reduced to empirical observation and data collection.

1920s—"thereof one must be silent."

This vision, in the various imaginings of Frege, Russell and the logical positivists, receives its most incisive and forceful articulation in Wittgenstein's *Tractatus Logico-Philosophicus* (Wittgenstein, 1921). Not a work on logic in the usual sense—it uses relatively little symbolism, almost no mathematics, and has none of the standard hallmarks of logical papers or textbooks—it nevertheless had great influence, and has continued to be read long after *Principia Mathematica* was relegated to relative obscurity of the history of logic. Indicative of what was deemed to be the new putative function of philosophy, the *Tractatus* took a long aim at the entire history of philosophy, portraying it as a discipline awash with metaphysical confusion. The following exemplifies this critique, but also suggests the putative manner in which philosophy *ought* to proceed—with surgical precision:

> 3.323 In the language of everyday life it very often happens that the same word signifies in two different ways—and therefore belongs to two different symbols—or that two words, which signify in different ways, are apparently applied in the same way in the proposition ...
>
> 3.324 Thus there easily arise the most fundamental confusions (of which the whole of philosophy is full).
>
> 3.325 In order to avoid these errors, we must employ a symbolism which excludes them, by not applying the same sign in different symbols and by not applying signs in the same way which signify in different ways. A symbolism, that is to say, which obeys the rules of *logical* grammar—of logical syntax.
>
> (The logical symbolism of Frege and Russell is such a language, which, however, does still not exclude all errors) (Wittgenstein, 1921, p. 41).

Wittgenstein's specific technical contribution to the discipline of logic in the *Tractatus* was limited to the construction of *truth tables*—a device for determining the truth function of a proposition given the truth values of its atomic parts. The broader influence of the *Tractatus* in philosophy, though, is inestimable—it completed the exercise instigated by Frege and Russell, of placing logic and linguistic analysis at the centre of contemporary philosophical discourse (Rorty, 1992). Just as significantly, once sufficiently interpreted and translated by Carnap, Ayer, Popper and others, it emphasised just how the factual propositions constituting scientific knowledge, specifically, were to be articulated—as a system of concepts, relations and properties. This was to form the basis for how modern knowledge systems would develop. Of anything which could not be subsumed directly within this system, logical positivists, following Wittgenstein, might declare: "thereof one must be silent" (Wittgenstein, 1921).

1930s—Completeness, Truth, Decidability and Computations

The 1930s witnessed a furious explosion of both theoretical work in logic, and the first emergence of its practical application. In the early years, two of the most significant figures in the history of logic, Tarski and Gödel, published vitally important results for the future evolution of knowledge systems. Neither's work is easily assimilable into a historical synopsis of this sort, so this section focusses only on two of their more significant results—published in Gödel's *Incompleteness Theorem* and Tarski's *Semantic Conception of Truth*, respectively. These results were to have near-immediate impact on the development of computing—around the middle of the decade, both Church and Turing delivered models of computation, and by the decade's end, quite independently, the first computer had been developed by Zuse in Germany (Lee, 1995).

Thereafter, the war was both to disrupt and furnish new opportunities for research in aid of the war effort, and, inadvertently, to establish a realignment of technological prowess with the diaspora of mathematical talent from the old to the new world.

In 1931, Gödel resolved the problem of providing a sufficient axiomatisation of the foundations of mathematics, albeit with a negative result. In his Incompleteness theorem, *On Formally Undecidable Propositions in Principia Mathematica and Related Systems*, he proved that a logical system could not be both complete and consistent. A system could only describe a complete set of theorems, such as those of arithmetic, by also admitting contradictory theorems. This result was to have vital implications—in Turing's re-casting of it several years later, the "halting" problem indicated that in the context of a hypothetical Turing machine performing an algorithm, it was impossible to decide whether it would terminate or run forever. This insight, vital to the general notion of computability, would also eventually mature into different classes of logic-based knowledge systems, depending on the trade-off between expressivity—what kinds of facts such systems can represent and reason over—and tractability—what guarantees of performance and termination reasoning algorithms would have (Nagel and Newman, 1959).

Tarski's work on formal languages has greater application still for the development of formal knowledge systems, and indeed has been highly influential in the philosophy of natural language, as Chapter 2 suggests. Although most of his work related to various fields in mathematics, several significant papers on logic published originally in Polish in the 1930s focus on the concept of truth in formal languages (Tarski, 1957). These papers form the basis for the development of model theory, which aims to describe how linguistic models (expressed in either formal or natural languages) can be adequately interpreted in a truth-functional sense. Tarski's relevant work from this period is the *Concept of Truth in Formalized Languages* (Tarski, 1957). The aim of the paper is to "construct—with reference to a given language—*a materially adequate and formally correct definition of the term 'true sentence'*" (Tarski, 1957). Tarski is careful not to offer a definition of truth itself—that task, he states, belongs to epistemology. Rather he is interested in answering the question: what is it for a sentence constructed in a given (formal) language to be true? An important step towards this result is the introduction of recursive languages, in which one language (a metalanguage) can be used to give the truth conditions of those in another (an object language). The metalanguage cannot however state the truth conditions of its *own* sentences—these conditions must be stated in yet another metalanguage. For Tarski, a sentence is true just in case there is a sentence in the metalanguage under consideration which is its translation. Tarski frames this result as a postulate known as *Convention T*. This semantic conception was eventually elaborated into model theory in the 1950s, and gave the precise semantic determination required for the construction of highly expressive formalisms, of which Semantic Web ontologies are a contemporary example.

Turing was another key figure who emerged in this period, building, as did Church, upon Gödel's critical insights. Although Great Britain had a diminished role in the development of computing in the post-war period, Turing remained a significant and iconoclastic influence in this development until his death in 1954 (Hodges, 2009). A member of the fervent Cambridge intellectual scene in the 1930s, Turing's work was to have greater practical consequence in the second half of the century than any of his contemporaries. The Turing machine, elaborated in an effort to solve the problem of mathematical decidability, was to form the basis of all of modern computers. Its key insight is that a machine can not only *encode* information, but also the very instructions for *processing* that information. This involved a virtualisation of the machine: from a pre-defined instruction set built into the machine itself, to one stored instead in "software"—a erasable, manipulable tape or script which now programmed the machine. Critically, these instructions then could be modified, so that the underlying physical machine would effectively be re-programmed using new algorithms to replicate any number of different "logical" machines. In the same paper, Turing also applied Gödel's incompleteness theorem to demonstrate the undecidability of certain algorithmic classes. Just as the broad vista of the computer age was sketched out in intricate detail via decidedly old-world metaphor of marked tape, ironically its theoretical horizon—the limits of computability—were also being discovered and announced.

1940s—Towards a Computational World

The work of Whitehead, Russell, Wittgenstein, Gödel, Tarski, Church and Turing, among many others, were to have substantial implications for modern computing applications, but in the 1930s these remained confined to the small communities of mathematicians and logicians. The first computers were developed in the late 1930s and the early 1940s, in Germany and in Great Britain respectively (Metropolis et al., 1980), and hence theoretical work in this field was only tentatively being applied to practical applications. Although Great Britain and Germany continued to produce the predominant logicians of this period, the prominence of Tarski and others attested to the broader interest in logic across the European continent, and increasingly, in the United States (Davis, 2001; Ceruzzi, 2003). The advent of the Second World War had two significant effects on the further development of logic and its application. First, it brought greater attention and funding to a range of theoretical disciplines, which suddenly appeared to have tremendous military application. The most conspicuous example was the development of the atomic bomb, possible only due to the recently realised theoretical feasibility of splitting atoms. But there was also significant developing of computing applications, notably in Britain and the United States—Turing's enduring fame is partly due to his code-breaking work on the Enigma project (Metropolis et al., 1980). Germany could also have entered the computer age in this period; Zuse, an enterprising young engineer, built the first functioning computer in 1938, but ironically could not obtain funding from the Nazi party to further its development (Metropolis et al., 1980; Lee, 1995). Second, with less immediate but equally great long term effect, the rise of Nazism and the war also stimulated the enormous migration of Jewish intellectuals to the United States in the 1930s and the early years of the war (Davis, 2001). This included, along with many others, both Gödel and Tarski, as well as von Neumann, a leading logician and economist, and also creator of the basic hardware architecture of the modern computer (Lee, 1995). This influx of considerable talent provided an enormous stimulus to American universities, noticeably at Princeton, Berkeley and Harvard. The preponderance of these intellectuals led, in the post-war period, to a generation of students who had been trained and influenced within the relatively sedate academic climate of the wealthy American university system. In the context of the Cold War and burgeoning economic conditions of the 1950s, highly trained mathematicians and physicists were to be increasingly in demand for both industry and government. The United States, and to a much lesser extent Russia, were well placed, then, to capitalise on the influx of significant intellectuals like Gödel and Tarski—although their influence was equally likely to be felt indirectly, through the work of their students, and the subsequent dissemination of their results via translation.

Although they form only a small part of the broader work conducted in mathematical logic, or as it was then termed, "metamathematics", the logicians introduced here still stand out as singularly responsible for both the disciplinary orientations of philosophy and mathematics, and setting the foundations for the extraordinary rise of the computing industry in subsequent years. In the latter part of the twentieth century, this quantitative growth itself led to significant qualitative specialisation in computing science, to the extent that the number of conferences, papers and results has long since been impractical to survey single-handedly. Even this appreciable academic activity pales in comparison, however, to the extraordinary industrial investment in computing applications. The next section aims to chart the direction of this development in the latter part of the twentieth century, especially in the context of the rise of knowledge systems. Of these, the relational database has had the most spectacular rise, to the extent it is now a pervasive part of any modern-day organisational infrastructure. The Semantic Web represents an effort to develop an alternative architecture for representing knowledge, featuring more expressive features than the set-theoretic models of relational databases. Collectively, however, they both represent species of a broader common genus, a family of formal knowledge systems which aimed to realise, with various inflections, the letter if not quite the spirit of Leibniz' much earlier utopic dreams.

6.4 Tables and Webs: Emerging Structures of Knowledge

6.4.1 Ordering the World by Relations

After the Second World War, and partially in response to the emergence of a new kind of conflict in which information was to become a central rather than peripheral military asset, the United States embarked upon a continuous and unabated course of research into a wide range of computing applications. At one end of the research spectrum was feverish, speculative and sometimes disappointing research into artificial intelligence, conducted by technology-oriented institutes like MIT. At the other end, companies and organisations like IBM, Xerox, DEC and the RAND Corporation developed their own, more commercially-oriented but still highly experimental research incubators, which frequently coordinated with their academic counterparts, often hiring bright PhD candidates with a firm eye on commercial applications (Ceruzzi, 2003). Government departments, particularly those associated with the military, often engaged researchers on various diverse computing projects, including cryptography, cybernetics, game theory and large-scale networking (Ceruzzi, 2003). It was the work of DARPA in the 1960s which gave rise to the first widespread computing networks, forerunners of the modern Internet. Frequently more prosaic areas of research, like networking, user interface development, typography and operating systems, yielded long-term and substantial gains. Attempts to emulate concepts as nebulous and little understood as human intelligence repeatedly hit low-lying hurdles—in the same period Chomsky was demonstrating just how complex one area of cognition, language acquisition and use, could be (Chomsky, 1965).

The rise of large commercial organisations operating over international territories increased the imperative to develop technologies for managing the expansive quantitative growth of information (Lyotard, 1984). In the 1960s, as computers grew in processing power and storage capacity, different methods were developed for managing volumes of structured information. A principal user of these technologies were the banking and insurance industries, for whom the need to provide reliable and systematic information on customers and transactions was paramount. Data storage at this time used a network or hierarchical model, where data records were linked in a parent-child relationship. Navigating from parent records (for example, from a customer) to children (to the customer's transactions) was relatively simple programmatically. However, the *ad hoc* aggregation of records based on relations which had not been previously defined in this manner—for instance, a request for all successful transactions within a given period—was time-consuming and computationally expensive. An industry group, the Database Task Group, comprising a number of leading technology companies, but notably excluding the market leader, IBM, proposed a so-called "network" model in the late 1960s (National Research Council, 1999). Both this approach, and IBM's subsequent alternative hierarchical model nonetheless continued to suffer the same limitations of performance and feasibility (National Research Council, 1999).

In 1969, in response to these limitations, an IBM employee, Edgar Codd, developed a rich algebra and calculus for representing data using what he termed a "relational model" (Codd, 1970). The model is comprised of several key concepts: *relations*, *attributes* and *tuples*—concepts which became known to designers and users of databases and spreadsheets under more familiar monikers of *tables*, *columns* and *rows*. Although this paper essentially proposes the application of set theoretical constructs to data models, it has a practical purpose—it explicitly aims to provide a better model for "non-inferential systems", unlike the early progenitors of research into artificial intelligence. The principal benefits of this model were to provide (a) a sufficiently abstract series of informational constructs which, once standardised, could allow for true data independence, and (b) a rigorous axiomatic system which could ensure data consistency (although as subsequent database administrators would discover, many other factors intrude upon the problem of maintaining a consistent data set). IBM itself was slow to follow up on the promise of its own innovation, and other elaborations of it which followed from its laboratories in the early 1970s. The company did develop a prototype system based on the relational model, called *System R*, but this failed to be adopted by IBM commercially (National Research Council, 1999). It did however publish its research on the relational model; and in 1977, after reading some of this research, three entrepreneurs founded what was soon to become the largest database company in the world, and one of the largest in the information technology sector (Oracle, 2007). Like Microsoft, Oracle's growth through the 1980s and 1990s was staggering—ironically, both companies profited from costly miscalculations at IBM. Though IBM was soon to catch up somewhat with its own commercial relational database system, Oracle's success was largely driven by, and indeed, cleverly anticipated the unrelenting drive of large organisations to manage enormous data sets. This was complemented by the increasing affordances of ever cheaper and more powerful hardware.

One of the principle advantages of the relational model is the provision of a standard and well-defined query language, SQL (Structured Query Language). In spite of fierce competition among database vendors, and a corresponding emphasis on product differentiation, SQL quickly became—and remained—an essential part of all modern database systems (Date, 2007). SQL was ratified as an US ANSI standard in 1986, and an international ISO standard in 1987, ensuring a minimal base compliance for manipulating and querying data across rival systems (Wikipedia, 2009). Unhappily for users of these systems, vendors like Oracle, IBM and Microsoft continued to extend the subsequent sequence of standards with various "proprietary" extensions—an earlier example of the dynamics of standardisation pursued in greater detail in Chapter 8. The preponderance of industry support for SQL demonstrates that even in the heavily competitive and nascent database software industry, vendors were prepared to trade-off short-term competitive advantage against the longer term positive network externalities of a larger marketplace built around selective feature standardisation and differentiation (Katz and Shapiro, 1985). As SQL became an integral component of modern computing degrees and certification processes, it demonstrated that English-like formal languages could achieve widespread adoption, with the significant incentive of a burgeoning job market in the 1990s and early part of the twenty-first century. Moreover it was no longer just the domain of large organisations—small-to-medium businesses and even keen individuals increasingly adopted relational databases as the basis for data management, usually with convenient user interfaces overlaid. The permeation of the relational data model into all aspects of computing culture represents the overwhelming and ongoing success of this paradigm for managing structured data (National Research Council, 1999). Indeed, the relational model represents, in a very direct sense, the culmination and fruition of the modernist dream to order and organise knowledge systematically.

6.4.2 Early Threads of the Semantic Web

The evolution of the Semantic Web, and its methods for representing knowledge, follow a decidedly different route. Since its earliest developments, when machines first replaced human "computers" (Davis, 2001), theorists and philosophers had been pondering the question of whether—and how—artificial intelligence was possible. The Turing Test, developed as early as 1950, suggested a range of criteria for determining how machine intelligence could be tested (Turing, 1950). Research in artificial intelligence was to proceed down numerous different lines over the remainder of the century, in pursuit of the often elusive goal of emulating human behaviour and cognition. Frequently denigrated for not realising its lofty ambitions, many AI innovations nevertheless filtered down from these comparatively abstract areas of research into everyday practical technologies. One area which received particular attention was the problem of modelling or representing knowledge—an essential step towards building computational equivalents of memory and reasoning processes.

In the 1960s, Quillian (1967) pioneered the idea of "semantic networks"—graphs of nodal concepts connected by associations, a precursor to neural networks. These were followed by more detailed models, such as semantic frames (Minsky, 1974). Semantic frames added the notion of "slots" to concepts, where their attributes could be stored. Abstractly, both attributes and relations could be considered as properties of a concept, distinguished only on the basis of whether a property could take a data value (attribute) or object value (relation). Semantic network and frame approaches were the basis of a number of early expert systems, with Minsky's proposals in particular galvanising interest in AI circles about the possibility of engineering computational approximations to human cognitive processes (Sowa, 2000). From another angle, there were various endeavours to instrumentalise theorem proving through use of declarative or logic programming languages (Colmerauer and Roussel, 1996). For whatever reason—perhaps because it was easier to separate knowledge bases from the procedures which reasoned over them—logic programming approaches were to remain a niche market. On the other hand, it soon became apparent that the sorts of things which constitute an "association" or "relationship" between concepts need greater semantic specificity than existing semantic network or frame approaches allowed. In 1979, a new system, KL-ONE (Brachman and Schmolze, 1985), emerged with more expressive semantics, where the kinds of relationships between conceptual nodes is explicitly stipulated. This was a step closer towards greater levels of interoperability between multiple knowledge systems; however, it was still possible to interpret constructs differently across different systems.

Over the course of the 1980s and 1990s, researchers began developing restricted forms of logic for representing knowledge (Sowa, 2000). "Terminological" or "description logics", as they became known, were fragments of first order logic with specific constructs for representing *concepts*, *properties* and *individuals* (Brachman et al., 1991). Significantly, description logics were directly derived from Tarksi's work on model theory discussed earlier, providing unambiguous interpretation of the effect of logical operations within conforming systems (Nardi and Brachman, 2003). For example, if a concept is stipulated as being subsumed by two other concepts, its *extension*—the objects denoted by the concept—must be interpreted as the union of the objects denoted by the parent concepts. For systems implementing these semantics, and for users of these systems, this feature ensured consistency in the handling of queries, and remedied many of the derivative problems which emerged in the implementations of earlier models (Nardi and Brachman, 2003).

Still, at this stage knowledge systems were invariably small scale—much too small to capture the many background facts assumed to sit behind the kind of common sense reasoning humans typically undertake. In 1984, Doug Lenat began a project called *Cyc*, which was intended to contain all of the facts which constitute an ordinary human's understanding of the world (Lenat, 2001). Development of the *Cyc* knowledge base is still ongoing, part of the commercial intellectual property of its owner, CycCorp, and represents a substantial undertaking to codify knowledge under the auspice of a single overriding conceptualisation (Lenat, 2001).

Proposals for the Semantic Web built on the work of description logics even more explicitly. Unlike Cyc, the vision of the Semantic Web involves *many* authors and conceptualisations, linked together by a common model-theoretic framework in RDF and OWL, explicit references and shared pointers to web resources. The explicit design goals of the Semantic Web were to provide a very general mechanism by which knowledge could be represented, shared and reasoned over computationally. The first published version of OWL came with different description logic variants, with different levels of expressivity and tractability—as the logic becomes more expressive, there are less guarantees that in the worst case reasoning problems are tractable, or can be resolved in finite time (Levesque and Brachman, 1987). Though its precursors, OIL (Ontology Inference Language) and DAML (DARPA Agent Markup Language), were first motivated by a combination of academic and military research, OWL itself quickly became sold to the broader web community as a facilitator for a new range of "intelligent" services—process automation, e-commerce, system integration and enhanced consumer applications (Fensel et al., 2001; Berners-Lee et al., 2001). RDF had similar, if more pragmatic origins as a language for data mark-up, with less emphasis on automated reasoning. It was, however, also motivated by the need to model information more flexibly than the highly structured models of preceding generations of data technology—notably the relational model—would allow. The document-centric nature of the World Wide Web suggested that significant amounts of information could not conform to the strictures of a relational view of the world. While being compatible with existing structured information sources was one constraint on the design of RDF, so too was the need to permit modelling of flexible, semi-structured, document-like and inter-connected data. The involvement of the World Wide Web Consortium ensured that the Semantic Web architecture, both technically and philosophically, built upon the foundations of the already—by the late 1990s, when the first formal Semantic Web technical recommendations were drafted—hugely successful precursor of the World Wide Web.

6.4.3 Shifting Trends or Status Quo?

Broadly, then, the Semantic Web can be seen as the consequence of three dominant broad trends in information technology and management over the later decades of the twentieth century. Firstly, organisations had grown in size; and commensurately, the burgeoning fields of business, management and information studies had encouraged the use of disciplined techniques for obtaining greater predictability over key variables in organisational operations. From the 1970s onwards, the explosive quantitative growth of data, the availability of and demand for computing resources for storing and processing it, and the increasing awareness of the opportunistic value of analysing it, led in turn to enormous investments in scientific research and development, as well as considerable financial speculation in the data management industry. This was primarily oriented around the relational data model—although other data storage models continued to be prevalent in specific fields, the general applicability of the relational model led to its near ubiquity as a mechanism for storing structured information.

Meanwhile, a second, less perspicuous trend took place in the ongoing research in artificial intelligence and knowledge representation, which in turn made feasible a well-defined and consistent notation for describing facts and permitting sophisticated inferencing operations. In fields with large numbers of concepts and very large amounts of data, such as medical, financial and military applications, the need for expert systems had long been evident.

Finally, the rise of the World Wide Web—the third, and arguably most disruptive of these trends—also brought new applications and therefore greater commercial relevance for deductive reasoning systems. Where the relational model had typically been used in intra-organisational (or even intra-departmental) settings, the advent of a global network, and the academic, economic and political advantages to be gained through its exploitation, made more evident than ever the need to supply unambiguous definitions of data through a highly expressive formal notation. The application of deductive reasoning to information from a myriad of sources gave rise to new problems of trust, proof and authentication, but also provided the tantalising prospect of unprecedented data being accessible to reasoning algorithms. The development of RDF and OWL were driven by the competing demands of providing notations simple enough, on the one hand, to be used and developed by software engineers and web developers untrained in knowledge representation, and expressive enough, on the other, to permit the kind of deductive power envisaged by the pioneers of AI, and indeed, by their precursors, the foundational logicians.

In spite of these evolutions, it would be premature to conclude that the Semantic Web is in the process of replacing the relational database. In fact the relational model has proved remarkably resilient in an industry recognised for inevitable if not always planned technological obsolescence. The massive commercial database industries still dwarf the largely academic and entrepreneurial world of the Semantic Web, and considerable work has been devoted to building bridging technologies between the respective formalisms—to promote, in fact, further use of the Semantic Web through connections to existing relational repositories of data (Malhotra, 2008). Meanwhile, many in the broader web community are also now examining alternatives to the Semantic Web itself, suggesting a more complex picture marked by overlapping, shifting trends rather than any clear pattern of technology phase-out (Khare and Çelik, 2006). At this stage it is more likely that both relational databases and Semantic Web ontologies will continue to be developed—making the question of their commensurability, discussed in the section below, highly pertinent.

6.5 Systems of Knowledge: Modern and Postmodern

These two models—the first, representing the fulfilment of modernist logicism, the second, a postmodern response and would-be successor—have special interest within a broader historical trajectory of formal systems. Relational systems hold, as mentioned above, a dominant position in the market of information systems. By one indicator—worldwide "total software revenue" (incorporating licenses, subscriptions, support and maintenance)—the relational database market grossed an estimated \$15.3 billion USD in revenue in 2006, \$16.8 billion USD in 2007 and \$18.8 billion USD in

2008, continuing to show strong growth rates in spite of a global economic downturn (Gartner, 2007, 2009). While this figure includes immediately subsidiary revenues accompanying software, it does not include the many development and maintenance tools, services, related or derivative systems which depend on relational database systems—a value likely to be much higher. Moreover, even an eventual meteoric rise of the Semantic Web does not imply the eclipse of the database industry, since, as suggested above, logical Semantic Web data structures like ontologies can be physically stored in a relational database; however, ontologies do present, as the analysis above shows, a rival conception of knowledge representation at a logical level, and also a separate tradition in a historical sense. Although they represent different logical formalisms, with few ontological commitments, nevertheless they can be distinguished on the basis of certain minimal and abstract assumptions. Perhaps the most contentious of these concerns the use of so-called "closed" versus "open" world assumptions, a distinction which has received substantial attention in the literature on logic, databases and knowledge representation (Reiter, 1987; Sowa, 2000). The following review examines this distinction in greater detail.

6.5.1 Closed versus Open World Assumptions

Reiter (1987) introduced "closed world" assumptions to describe the interpretation of an empty or failed query result on a database as equivalent to a negation of the facts asserted in the query: "In a closed world, negation as failure is equivalent to ordinary negation" (Sowa, 2000). In other words, the set of facts contained in a database are assumed to be complete descriptions of a given domain of discourse—any proposition not either directly stated or indirectly inferrable is interpreted to be *false*. In contrast an assumption of an "open world" interprets the absence of a proposition as indicating its truth-value is *unknown* (Date, 2007). One way of characterising this difference, then, is to say that a "closed world assumption" interprets failure *semantically*—directly, as a false proposition—where an "open world assumption" interprets failure *epistemologically*—indirectly, as a failure of *knowledge* about the semantic state of the proposition [1]. An important consequence follows, related to the properties of the logics which underpin these interpretive systems. Under open world assumptions, reasoning is *monotonic*—no new information added to a database can invalidate existing information, and the deductive conclusions which can be drawn from it (Sowa, 2000). Reasoning is essentially additive—new facts added to the database always increase the number of conclusions which can be drawn. In the extreme case, if a new proposition contradicts something already stated, *every* proposition is rendered provable. Conversely, *nonmonotonic* reasoning is revisionary—new facts can revise existing conclusions. Depending on the scope of new facts, the sum of conclusions derivable from a database can accordingly increase or decrease. In logical terms, if a conclusion C is derivable from a premiss A, but not from the conjunction of A and

[1] This distinction is analogous to that between frequentist and Bayesian interpretations of probability.

a further proposition B, then the mode of reasoning must be nonmonotonic (Hayes, 2004).

Matters are further complicated with the introduction of *context*. As Hayes (2004) note:

> The relationship between monotonic and nonmonotonic inferences is often subtle. For example, if a closed-world assumption is made explicit, e.g. by asserting explicitly that the corpus is complete and providing explicit provenance information in the conclusion, then closed-world reasoning is monotonic; it is the implicitness that makes the reasoning nonmonotonic. Nonmonotonic conclusions can be said to be valid only in some kind of 'context', and are liable to be incorrect or misleading when used outside that context. Making the context explicit in the reasoning and visible in the conclusion is a way to map them into a monotonic framework.

Consequently it is possible to augment a set of propositions, interpreted under local closed-world conditions, with explicit contextual information—temporal, spatial, providential, jurisdictional, functional—to move towards an open-world interpretation essential to the unconstrained environment of the Semantic Web. Since specifying context is itself an open-ended affair, this suggests interpretation moves across a scale of "closed-open worldliness"—a point also suggested by Sowa (2000): "Reiter's two categories of databases can be extended with a third category, called *semi-open*, in which some subdomains are closed by definition, but other subdomains contain observed or measured information that is typically incomplete". Conversely, Date (2007) disputes that anything approximating to open world reasoning ever takes place, even on the Semantic Web—this would entail an unacceptable ternary logic, as though the epistemic predicate "unknown" could sit alongside the semantic predicates of "true" and "false". It is worth noting that there is incommensurability here even at the level of definition—by, as it happens, noted authorities on the Semantic Web (Hayes) and the relational model (Date) respectively. Interpreting commensurability of systems distinguished by this assumption depends, then, on how the assumption itself is viewed: as an epistemological question over the nature of non-existent information; as a scale against which the state of information of a database can be measured; or as a nonsensical category.

6.5.2 Modern Grids, Postmodern Webs

These properties of logical interpretation are not unconnected from the cultural environs in which database systems are used. Indeed, it is precisely because of the unusual usage conditions of the Semantic Web that "open world assumptions" and non-monotonic reasoning are considered significant in this context. As Date (2007) notes, the "closed" metaphor has an unfortunately pejorative connotations—but ironically parallels the closedness of the cultural contexts in which systems with closed world assumptions are likely to be used. As the tracing of their respective evolutionary paths above suggests, the Semantic Web is largely derived from academic research; conversely, relational databases originate in commercial and organisational environments. The connotations of these institutional settings impacts on the contemporary reception of the formalisms themselves. The following section examines remarks made by online commentators in response to these cultural allusions.

Numerous media articles and bloggers have commented on the apparent threat and "disruptive innovation" of the Semantic Web to the prevailing relational database paradigm. Familiar tropes heralding the "shock of the new" are common in the more hyperbolic of media reports. Several blog articles presage the "death" of the relation database model[2], while one blogger eulogises the rise of RDF and OWL[3], delivering an acute characterisation of the perceived distinction between old and new models:

> The single failure of data integration since the inception of information technologies—for more than 30 years, now—has been schema rigidity or schema fragility. That is, once data relationships are set, they remain so and can not easily be changed in conventional data management systems nor in the applications that use them.
>
> Relational database management (RDBM) systems have not helped this challenge, at all. While tremendously useful for transactions and enabling the addition of more data records (instances, or rows in a relational table schema), they are not adaptive nor flexible.
>
> Why is this so?
>
> In part, it has to do with the structural view of the world. If everything is represented as a flat table of rows and columns, with keys to other flat structures, as soon as that representation changes, the tentacled connections can break. Such has been the fragility of the RDBMS model, and the hard-earned resistance of RDBMS administrators to schema growth or change[4].

Other commentators portray the shift towards the Semantic Web in similarly revolutionary terms:

> To me, the Semantic Web is a fundamental shift in software architecture[5].

> The relational database is becoming increasingly less useful in a web 2.0 world[6].

[2]Lunn (2008); Williams (2008); Zaino (2008). In this and the following two case studies, primary sources are footnoted in this manner, while secondary sources continue to be cited inline. The distinction is not always clear-cut here, as some sources could be considered either primary or secondary. However, the context should make clear how a source is being treated.
[3]Bergman (2009).
[4]Bergman (2009).
[5]Kolb (2008).
[6]Williams (2008).

On the other side of the coin, many voices have decried the complexity, redundancy and eccentric design of the Semantic Web, which intentionally introduces an "impedance mismatch" with mainstream information technological infrastructure, notably the world of relational databases and associated tools and expertise. An early and infamous critique ironically postulated that the Semantic Web was a purist academic exercise designed to homogenise the world's information under a complex architecture, requiring both a deductive logic and a single global ontology, and with little practical likelihood of adoption and uptake:

> This is the promise of the Semantic Web—it will improve all the areas of your life where you currently use syllogisms.
>
> Which is to say, almost nowhere[7].

More nuanced critiques have emphasised the beneficial character of *de facto* standards, preferring the gradual refinement undergone in practical situations and use to the imposition of *de jure* standards:

> The best standards are the ones that develop "from below" through widespread use. Then the job of the standards committees is to recognize what is already being used, to tidy up the details, and to solidify the foundations[8].

The articulation of these positions tend to congeal around several common metaphorical tropes. The Semantic Web is open, free, "bottom-up", democratic. The relational database is closed, secure, solid, robust, "top-down", controlled. The Semantic *web* conveys a chaotic sprawling information network or graph, without apparent origin, centre or terminus. The relational database is housed within the "back office" of the modern-day enterprise, whose grid-locked modernist architecture mirror structured data sets, with rectilinear tables, columns, rows and cells. The Semantic Web is broad, visionary, idealistic, experimental, revolutionary, part of Web 2.0, 3.0 or even some futuristic variant; the relational database is mature, well-understood, pragmatic, workable, third or fourth generational technology, protected by corporate support. Where the Semantic Web famously envisions a world in which "information wants to be free"—a phrase originating in an earlier period of computing infused with libertarian ethos (Clarke, 2001), but often applied to the Semantic Web movement equally—relational databases are often portrayed as siloed repositories of hermetically sealed, "closed" organisational data, carefully managed by government and corporate enterprises and departments—the catch-cry of this world might be instead "no-one ever got fired for choosing IBM". The world of the database is a de-humanised, administered, bureaucratic, orderly, modernist *Gesellschaft*; the semantic web instead an interconnected, uncontrolled, chaotic and postmodern *Gemeinschaft*.

These metaphorical caricatures ignore numerous confounding elements: for example, Semantic Web data (RDF and OWL ontologies) are capable of being stored in

[7] Shirky (2003).
[8] Sowa (2007e).

relational databases, and relational databases have for some time supported a range of technical connectivity options. It might well be argued that benevolent synergies between styles of systems makes for less interesting debate, and less opportunity to differentiate products and services which depend on perceived friction and dissonance. More august commentary is provided by Tim Berners-Lee, suggesting, very early in the development of the Semantic Web, that the major differences are superficially syntactic, rather than semantic, ontological or epistemological:

> The semantic web data model is very directly connected with the model of relational databases . . . The mapping is very direct[9].

Considerable commercial and academic research has also been directed towards hybrid and bridging technologies between relational databases and the Semantic Web, as the report by Malhotra (2008) suggests. Some of these involve simply publishing relational data as RDF; others use relational models to capture RDF and OWL ontological axioms directly; still others provide mappings between proprietary XML and other formats and standard RDF. Current trends tend towards conciliation—perhaps as both positive and negative hysteria around the Semantic Web changes into a more mature recognition of its role, as something neither entirely central nor tangential, in modern system engineering.

6.5.3 Assessing Commensurability

Some points of historical, technical and sociological contrast have been elaborated in the discussion of knowledge systems above. What does this analysis imply for an assessment of the commensurability of the systems? The table below picks up several of the generic dimensions presented in Chapter 5 to characterise at least what are perceived differences in the systems. These have been selected largely because they have emerged as distinctive in the analysis above. Several addition dimensions have also been added—"Open World Assumptions", "Interconnected with Other Systems", "Trusting of Other Systems" and "Multi-modal" (meaning multiple generic "modes" of information are supported—qualitative or quantitative; structured or amorphous; textual or multimedia)—which are particularly relevant to this comparison. Each of the dimensions is rated only in approximated quantitative terms—since the assessment here is designed to exercise and explore the framework, and has no obvious practical assessment, there are no clear grounds to be derived from a situation context for weighting and valuing the dimensions more precisely. Nevertheless it is possible to see a general outline emerge in the evaluations below.

[9] Berners-Lee (1998/2009).

Table 6.1: Comparison of Knowledge Systems

Dimension	**Relational Model**	**Semantic Web**
Orientation		
Open World Assumptions	Low	High
Interconnected with Other Systems	Low	High
Trusting of Other Systems	Low	High
Multi-modal	Low	High
Pragmatic—Idealistic	Low	High
Academic—Applied	High	Low
Speculative—Grounded	High	Low
Purpose		
Financially Motivated	High	Low
Politically Motivated	Low	Moderate
Process		
Central—Distributed Design	Moderate	High
Closed—Transparent Process	Moderate	High
Reception		
Low—High Adoption Rate	High	Moderate
Low—High Maturity	High	Low
Backwards Compatibility	High	Moderate
De Facto Standard	High	Low
De Jure Standard	High	High
Industry Support	High	Moderate

In terms of public perception and adoption, in particular, the analysis suggests the two systems are broadly incommensurable. One key dimension, *Open World Assumptions*, suggests a potentially insurmountable difference in orientation between the two formalisms. As the analysis above suggests, evaluating the effect of this distinction in particular depends critically on how radically it is interpreted. Several interpretations were suggested: Date, for example, views the distinction itself as the product of a confusion of semantic and epistemological boundaries; for Hayes, the distinction can be erased through the explication of context; for Sowa, the distinction is a gradual one, as system "subdomains" can be either closed or open; for other commentators (Kolb, 2008; Williams, 2008; Bergman, 2009), the division is instead indicative of more fundamental incommensurability. Assessing the very possibility of translation between systems falling on either side of this assumption depends, then, on which of these interpretations are adopted.

In relation to the broader social dimensions, the interest in the Semantic Web has paralleled the phenomenal growth of "libertarian" technologies: commoditised computing hardware and connectivity, open source software, standards and protocols, and the World Wide Web itself. Sympathies with these ideals might emphasise stronger incommensurability with older, industrial and bureaucratic technological models like the relational database. However, the relation between the knowledge *system* and its field of application is far from a direct one—relational databases also benefit from open standards; and a number of database products have been released as open source. Equally, the Semantic Web has suffered from the perception that it is overly complex and immature relative to its older representational sibling. How much of this critique will endure in the face of further research and emerging industry supports remains to be seen.

As suggested much earlier in the historical account, lurking within the deep divisions of epistemological assumptions between these two formalisms is an even deeper epistemological affinity—a putative view that knowledge can be heavily structured, organised, cleaned and disambiguated from its natural language expression. Insofar as formalisms can be contrasted, the salient contrastive features necessarily suggest difference over similarity. It is only when positioned against broader epistemological frames—which might dispute the very project of rendering knowledge faithfully in denuded formalistic terms—that this deeper affinity is exhibited. In moving towards other, more fine-grained domains of comparison and commensurability, this irreducibly contextual aspect of assessment needs to remain prominent.

6.6 Knowledge Systems in Social Context

To round out the discussion of knowledge systems, the following summary also teases out what was an underlying thread in the account above—the relationship between technological innovation and broader social shifts. These shifts exhibit a complex network of causal relationships to the general processes of technological design, development and innovation, and hence, to the question of commensurability between rival systems that emerge from these processes. These relationships, tenuously charted in this study, are more explicit in the studies that follow.

In the last quarter of the twentieth century the development of formal knowledge systems has been precipitous. The preceding discussion showed how this ascent was premised upon the foundational work in mathematical logic in the late nineteenth and early twentieth centuries. Leibniz's dream—of a single symbolic language in which thoughts and argument could be conducted without ambiguity—was a constant motif throughout the evolution of this tradition. Symbolic logic, then, represents a pristine formal component of a long-ranging historical epistemological ideal, while an endless accumulation of "sense-experience" supplies the matter. The Semantic Web represents a modern-day re-casting of this ideal, in which precise agreement about meaning forms the underlying substrate for sharing information and deducing inferences. It receives its most emphatic expression from Ayer, who envisioned philosophy and science of ardent empiricism:

> The view of philosophy which we have adopted may, I think, fairly be described as a form of empiricism. For it is characteristic of an empiricist to eschew metaphysics, on the ground that every factual proposition must refer to sense-experience (Ayer, 1952, p. 71).

The unfolding of this tradition in the account above describes three key phases—classicism, modernism and postmodernism. These phases show an increasing impulse towards the development of "taxinomia"—indexable, searchable and interoperable knowledge systems which span from the globally networked enterprise down to the fragmentary databases of commercial and social interactions managed by individual consumers. By tracing this tradition through a purely intellectual history, it is possible to suggest several causal factors internal to the tradition itself: the production of particular fortuitous mathematical results, or a sense of exhaustion with the preceding metaphysical speculations of Kant and Hegel, for example. It is equally possible, though, to plot lines of concordance between this intellectual history and broader transitions in economic and political history. Is it purely fortuitous that the search for logic formalisms coincided with a reciprocal drive towards standardisation, in a host of technological, communicative and legal fields, that is related to modern capitalism—specifically, of its relentless need and demand for predictability and efficiency? For Foucault, the modern taxonomic impulse originate alongside the great social and political shifts of the Enlightenment:

> What makes the totality of the Classical *episteme* possible is primarily the relation to a knowledge of order. When dealing with the ordering of simple natures, one has recourse to a mathesis, of which the universal method is algebra. When dealing with the ordering of complex natures (representations in general, as they are given in experience), one has to constitute a *taxinomia*, and to do that one has to establish a system of systems (Foucault, 2002, pp. 79–80).

By the time of the emergence of formal logic in something like its rigorous modern form in the nineteenth century, the world was also undergoing a period of rapid economic expansion, industrialisation, scientific endeavour and technological innovation (Hobsbawm, 1975). Already the opportunities of standardisation were being considered in a host of practical contexts—rail gauge standardisation, currency exchange, scientific notation, legal charters and academic disciplinary vocabularies. The counterweight to international and inter-corporate competition was the beneficial network externalities—greater efficiency, information transparency and intelligibility—these standards would bring. Since these first standards emerged, their growth has been rapid—the ISO website alone presently advertises 17,500 separately catalogued standards (ISO, 2009).

While standardisation might rightly seem, then, to be an inextricable feature of modernity, coupled with economic globalisation and cultural homogenisation, it can equally be argued that capitalism also harbours countervailing trends towards systemic differentiation. Most notably in the case of the quintessential capitalist organisation, the *company*, product or service differentiation forms the foundation for market share, profit, and thus for increasing shareholder value. To take one metric of the extent of differentiation, at the level of invention and innovation: the US Patent Office has filed over seven million utility patents alone since 1836 (United States Patent and Trademark Office, 2009), with an average *rate of increase* in the number of patent applications between 1836 and 2008 of 23.5%. In 1838, 436 patent applications were filed; in 2008, 158,699 applications were filed, an overall increase of 36,398% over 170 years[10]. Whatever explanation of drift towards standardisation can be drawn from modern capitalism, there is an equivalent burden for explaining a similar level of hyper-activity towards proprietary protection of intellectual capital and assets.

Equivalent, if more tenuous motives for differentiation can be found in other organisational types—political affiliations, methodological distinctions and sublimated competitive instincts exist in government, scientific and academic institutions as much as in corporate ones. The development and coordination of knowledge systems—formalised representations of meaning—has its origins, in one side of modern capitalism, in the impulse to order, organise and predict. The proliferation of multiple systems represents, then, another facet of capitalism—the need for differentiation and competition. Schumpeterian "creative destruction", describing the process by which capitalism continually cannibalises its own monuments with successive waves of technological and procedural innovation, captures something of these apparently contradictory impulses towards both standardisation and differentiation at the level of systems of meaning. However, as this and the following studies show, other, less tangible vectors can also be seen influencing the mutations of these systems.

At this stage, though, it is sufficient to draw out the coincidental tendencies between the specific phenomenon of the emergence of knowledge systems and the much broader chameleonic shifts of capitalism, without pursuing too strong an attribution to determining causes. The following studies bring out other complicating and more fine-grained features of the contexts in which these systems emerge, and of the factors which influence their respective differentiation.

[10]The raw data has been taken from (United States Patent and Trademark Office, 2009)—the percentile calculations are my own.

Chapter 7

Case Study: Upper-Level Ontologies

> Expressions which are in no way composite signify substance, quantity, quality, relation, place, time, position, state, action, or affection. To sketch my meaning roughly, examples of substance are 'man' or 'the horse', of quantity, such terms as 'two cubits long' or 'three cubits long', of quality, such attributes as 'white', 'grammatical'. 'Double', 'half', 'greater', fall under the category of relation; 'in a the market place', 'in the Lyceum', under that of place; 'yesterday', 'last year', under that of time. 'Lying', 'sitting', are terms indicating position, 'shod', 'armed', state; 'to lance', 'to cauterize', action; 'to be lanced', 'to be cauterized', affection (Aristotle, 1994, p. 4).

The following case study examines the field of "upper-level", or foundational, ontologies. In the past ten years a number of upper-level ontologies have been developed to establish a set of concepts and definitions which could be shared by lower-level, domain ontologies. A good upper-level ontology should aim to:

- promote design modularity, by abstracting common concepts from domain ontologies;
- encourage reusability by domain ontologies, by providing useful concepts which do not need to be re-specified by those ontologies;
- enhance interoperability among domain ontologies, by providing common points of reference.

"Upper-level" ontologies are therefore one approach to the problem of commensurability for domain-level ontologies. By establishing a core set of abstract concepts, use of an upper-level ontology by domain-level ontologies is at least some guarantee of a shared metaphysical orientation. For example, several upper-level ontologies surveyed below make a fundamental distinction between "endurants" and "perdurants", or in another vocabulary, "occurrents" and "continuants". Roughly, this conceptual pair distinguishes things which take place *in* time—such as events—from those which exist *through* time—such as material objects. Domain-level ontologies which import an upper-level ontology making this distinction can be said to inherit this conceptual distinction too. So two such ontologies can at least be said to be commensurable insofar as their subordinate conceptual classes are distinguishable as either event-like endurants or object-like perdurants. Use of the OWL syntactic `imports` construct to import an ontology does not guarantee that all—or even any—of its semantic commitments are inherited in this way, but does provide a starting point for domain-level ontologies to establish points of connectivity and interoperability.

Inevitably there has been competition in the development of upper-level ontologies. Rather than answer questions of compatibility and commensurability among domain-level ontologies, then, this has served to redirect these question towards the upper-level ontologies themselves. In a scenario where two domain-level ontologies import and use *different* upper-level ontologies, a matching task may need to establish concordance between the concepts specified in both the domain-level and upper-level ontologies. Moreover, precisely due to the abstraction of conceptualisations specified in the upper-level ontologies, these matches become considerably more difficult to establish, especially by purely algorithmic means.

The first part of the study below surveys five ontologies developed in the OWL language over the past decade, to examine what sorts of evaluation of commensurability can be made about them. As well as using the framework established in Chapter 5, this study also makes use of some earlier comparative work by Oberle et al. (2007). All of the ontologies were developed by academic groups, with some level of industry and government input. One side effect of this method of development, and of the relative obscurity of upper-level ontologies, is that while there are more or less corresponding academic publications for each of the ontologies, it is comparatively difficult to understand much of the motivations, reasons and processes by which the ontologies are developed. To date, the ontologies are not widely used either, making it difficult to understand how they are used in derivative domain-level ontologies. To combat this, the second part of the study also examines two public mailing lists (the *Semantic Web* and *Ontolog Forum* lists), where many of the issues relating to upper-level ontologies are debated, and several of the ontology authors themselves also appear. A series of quantitative and qualitative techniques are used to elicit clarification of several of the distinctions developed in the review of ontologies. The study then concludes with a general assessment of the commensurability of the ontologies, and some notes on potential implications for the overall model of commensurability developed thus far.

7.1 A Survey of Upper-Level Ontologies

The following survey describes the ontologies in terms of five specific features:

- Background *contextual information*
- Stated or implied *methodologies*
- Explicitly stated *assumptions*
- *Structural* features
- Key *concepts* and *categories*

The survey covers five published upper-level ontologies which have expressed in the Web Ontology Language (OWL), version 1.0 (Hayes et al., 2004). These ontologies are: Basic Formal Ontology *(BFO)*[1], PROTo ONtology *(PROTON)*[2]; General Formal Ontology *(GFO)*[3]; Descriptive Ontology for Linguistic and Cognitive Engineering *(DOLCE)*[4]; and Standard Upper Merged Ontology *(SUMO)*[5].

7.1.1 Background

The upper-level ontologies surveyed are developed within academic, or joint academic-government initiatives, sometimes as part of larger projects. For example, the BFO ontology has been developed within the Institute for Formal Ontology and Medical Information Science (IFOMIS), utilising a grant to "develop a formal ontology that will be applied and tested in the domain of medical and biomedical information science"[6]. Similarly the DOLCE ontology has been developed as part of "EU IST integrated project Semantic Knowledge Technologies (SEKT)", a project funded by the "EU 6^{th} Framework programme"[7]. Two of the ontologies—BFO and GFO—have been developed with specific focus on medical classification applications. The institutional nature of ontology engineering is common to domain-specific ontologies also, although several popular ontologies have been developed in the public domain, without any notable institutional involvement—the Friend of a Friend (FOAF) ontology is one such example[8].

All of the ontologies have been developed in Europe, with the exception of SUMO, developed in the United States. Each of the ontology results have been presented at semantic web-related conferences—suggesting that, at time of publication, upper-level ontologies generally have been of greater interest to academic communities than either commercial or software engineering communities. In addition, there are numerous academic publications which cite these ontologies or the papers describing them, either

[1] Grenon (2003a). Note that as with the other studies, sources treated as primary are cited as footnotes rather than inline.
[2] Terziev et al. (2004).
[3] Herre (2009).
[4] Masolo et al. (2002).
[5] Niles and Pease (2001).
[6] IFOMIS (2007).
[7] Semantic Knowledge Technologies (SEKT) (2007).
[8] FOAF (2007).

in the context of ontology engineering specifically, or in relation to broader ontological questions.

Many of the authors of findings actively contribute to public domain mailing lists where ontology engineering issues are discussed. For example, Barry Smith and John Sowa have been actively involved in the construction of two of the featured ontologies (BFO and SUMO respectively), and also have contributed extensively to mailing lists analysed further on in this analysis. In spite of the lack of mailing lists or other discursive sources dedicated to the surveyed ontologies themselves, there is active online debate about the sorts of concepts and distinctions which feature in upper-level ontologies generally. An analysis of these mailing lists is presented in further detail below.

At time of writing it is difficult to measure the relative impact of the ontologies quantitatively. For the purpose of the survey, two sources have been used to indicate the impact:

- Results from *Swoogle*, a semantic web search engine (Ding et al., 2004);
- Citation counts from *Google Scholar* in relation to the titles of key papers presenting the ontologies.

Results have been collated from Swoogle and Google Scholar searches conducted in October, 2007 and October, 2009. They are presented in tables 7.1 and 7.2.

Table 7.1: Swoogle Results

Ontology	**Search Term**[a]	**2007**	**2009**
BFO	"BFO"	10	135
PROTON	"Proto Ontology"	5	10
GFO	"GFO"	10	38
DOLCE	"DOLCE"	108	157
SUMO	"SUMO"	92	121

[a]The "Search Term" is the actual text searched for, in order to disambiguate ontology names or acronyms from other names. In the case of "Proton", for example, the ontology title is also the name of a physical object (positively sub-atomic particle).

The comparison between Swoogle and Google Scholar show a positive correlation of 0.67 for the results in 2007, and a weaker correlation of 0.37 for those in 2009. With the exception of the large number of ontology references for BFO, DOLCE and SUMO are more prominent both in terms of ontologies references and citations. This does not take into account private usage of these ontologies, but provides a useful heuristic of present adoption rates. It indicates also the increased use of upper-level ontologies over time, according to both of the metrics used, with numbers roughly doubling on average over the two year period for all ontologies surveyed. As mentioned, the BFO ontology experienced a large surge in number of ontology references—this abnormal

Table 7.2: Google Scholar Results

Ontology	**Search Term**[a]	**2007**[b]	**2009**
BFO	"Spatio-temporality in Basic Formal Ontology"	11	13
PROTON	"Base upper-level ontology (BULO) Guidance"	9	19
GFO	"General Formal Ontology (GFO)"	2	12
DOLCE	"The WonderWeb Library of Foundational Ontologies"	71	168
SUMO	"Toward a standard upper ontology"	356	773

[a]In this case the "Search Term" is the name of the main paper in which the ontology is presented. The same paper can be listed several times in results (for example, as both conference proceedings and technical reports); the citation counts have been totalled where this has occurred, and also where the citation count is greater than 1.
[b]Both 2007 and 2009 figures refer to the aggregate number of citations as reported by Google Scholar.

jump appears to the result of widespread references from newly developed biological ontologies housed by the OBO Foundry, which the BFO was designed to support[9].

It is also worth noting there have several prominent efforts at upper-level ontologies which predate the emergence of OWL as a standard for modeling ontologies:

- Cyc
- WordNet
- Standard Upper Ontology (SUO)

These are expressed in different formalisms, and so are not amenable to algorithmic comparison with those expressed in OWL. The SUMO ontology is explicitly indebted to the SUO ontology (Niles and Pease, 2001), and most of the ontologies described have some level of mapping to WordNet—a publicly available online dictionary which links words based on semantic relations (Miller, 1995). Cyc is an older and well-established representation of both upper-level and domain-level knowledge[10], developed privately by CycCorp—it is frequently cited in the literature on upper-level ontologies (and knowledge representation), but for reasons of both its proprietary nature and different formal structure, it is not available for direct comparison.

Finally, as discussed at further length in the *Assumptions* section below, several of the upper-level ontologies have been developed with awareness of competing ontologies, and so reference distinctions between them explicitly. For instance, the GFO ontology is compared with SUMO and DOLCE by its authors[11]; the BFO ontology is compared with DOLCE[12]; the PROTON ontology references both WordNet and

[9]IFOMIS (2007).
[10]Lenat (1995).
[11]Herre (2009).
[12]Grenon (2003b).

CYC[13]; and the SUMO ontology, as mentioned, is itself compiled from both SUO and a range of other sources:

> The SUMO was created by merging publicly available ontological content into a single, comprehensive, and cohesive structure. This content included the ontologies available on the Ontolingua server, John Sowa's upper level ontology, the ontologies developed by ITBM-CNR, and various mereotopological theories, among other sources[14].

There has also been a certain amount of *post facto* literature comparing DOLCE and SUMO in particular (the innovatively entitled *DOLCE ergo SUMO* (Oberle et al., 2007) and *OntoMap* (Kiryakov et al., 2001) being two such examples). This activity suggests that ontology engineering is a highly dynamic social process, and at the present time, still far from finding agreement for the abstract concepts upper-level ontologies describe. The engagement with the mailing lists—the informal "chatter" which sits behind the formal austerity of ontologies—explores this dynamic and dialogical process further.

7.1.2 Methodologies

The methodologies outlined in the literature surrounding upper-level ontologies vary from highly explicit (SUMO) to implicit (PROTON). Table 7.3 represents an overview of the methodological approach adopted—as best as can be inferred if not otherwise stated—and the degree of formality of process of ontology construction.

The variance in methodology (both in terms of the adopted approach itself, and the degree of explicitness *about* the approach) is one indicator about the degree of commensurability between upper-level ontologies. How concepts are selected and arranged can divulge further assumptions not explicit in the conceptualisation. However even in the case of the SUMO ontology, little is stated about how one concept was chosen over another: what leads to a particular arrangement of concepts, beyond an acknowledgement of certain existential assumptions, and what degree of detail is suitable. Arguably methodology is harder to apply to *upper-level* ontologies especially, given the abstractions of the concepts concerned. The later discussion returns to this variance, since it has a bearing on what can be said about the commensurability of these ontologies.

7.1.3 Assumptions

None of the upper-level ontologies surveyed lay great pretensions towards definitiveness; the authors of DOLCE for instance state "we do *not* intend DOLCE as a candidate for a 'universal' standard ontology"[15]. In the literature showcasing the

[13] Terziev et al. (2004).
[14] Niles and Pease (2001).
[15] Masolo et al. (2002).

Table 7.3: Ontology Methodologies

Ontology	Methodology	Degree of Formality
BFO	Draws on an explicit account of philosophical ontology[a]	Moderate
GFO	Draws on abstract conceptualisations presented in philosophical literature (Brentano, Husserl, Hartmann, Ingarden, Johansson, Searle)	Moderate
PROTON	Designed as a "light-weight" ontology, modeled on "common sense"[b]	Low
SUMO	Identifies a range of prior ontologies, including SUO; ensures each identified ontology is *syntactically* compatible; performs a manual *semantic* merging of the ontologies	High
DOLCE	Unknown (seems to rely upon prior research)	Moderate

[a]Grenon and Smith (2004).
[b]Terziev et al. (2004).

ontologies, their designers are overtly aware of the assumptions which characterise their construction[16]. Nevertheless there are clear differences in these assumptions, both in kind and degree. The following section examines both what assumptions are employed, and how these compare.

BFO

The Basic Formal Ontology (BFO) is by far the most explicit about the assumptions the authors employ in its design. The three papers outlining the BFO are presented alongside six other papers authored or co-authored by Smith, heavily directed towards justification of a philosophical orientation of "realist perspectivalism"[17]. This is characterised by "the view that any given domain of reality can be viewed from a number of different ontological perspectives, all of which can have equal claim to veridicality"[18]. Realist perspectivalism avoids two key fallacies of ontology engineering, in Smith's views: on the one hand, those inherited from "idealist, skeptical, or constructionist philosophy", which "appear commonly in the wider world under the guise of postmodernism or cultural relativism"[19]; and on the other, those incurred through too enthusiastic an adherence to predicate logic and the stark ontology of its formalism—a brand of philosophy described by Smith as "fantology"[20]. This latter

[16]Grenon (2003b); Masolo et al. (2002).
[17]BFO (2007); Smith (2004).
[18]Smith and Grenon (2004).
[19]Smith (2004).
[20]Smith (2005).

kind of fallacy has, for Smith, been perpetuated by logicians since Frege:

> But [Frege's] signal achievement was for a long time marred by its association with an overestimation of the power of a relatively simplistic type of logico-linguistic analysis to resolve ontological problems. Exposing some of the effects of this overestimation should allow us to understand the development of analytical philosophy in a new way, and to bring to light aspects of this development which are normally hidden[21].

Smith's alternative, which forms the guiding principle of the BFO's construction, is admit perspectivalism only in *veridical form*, that is, only insofar as any given perspective is corroborated by natural science:

> But perspectivalism is constrained by realism: thus it does not amount to the thesis that just any view of reality is legitimate. To establish which views *are* legitimate we must weigh them against their ability to survive critical tests when confronted with reality, for example via scientific experiments[22].

In this paper, the realist perspectivalist account is augmented with *fallibilist* and *adequetist* qualifiers. Smith names philosophical precursors to this account are Aristotle and Husserl—though, with similarities to the GFO assumptions discussed later, Husserl is mediated by Ingarden's *realist* phenomenology.

A pivotal difference between the approach promulgated by Smith and Grenon in their introductory paper to the BFO, and the unified reductivist ontology they critique, concerns the treatment of *time*, or in the more particular words of the authors, different "Temporal Modes of Being"[23]. Smith and Grenon devote considerable attention to the distinction between 3D and 4D perspectives (which they translate into the more convenient monikers "SNAP" and "SPAN"[24]. According to the perspectivalist account, a generalised account must be capable of reflecting *both* perspectives (otherwise it falls on the side of a reductivist account, privileging a single perspective). The 3D/SNAP perspective treats entities in the world as *continuant* or *endurant* (entities which exist *wholly* at some point in time). The 4D/SPAN perspective treats entities as *occurrent* or *perdurant* (entities which exist only *in part* at any point in time). Each perspective is assumed to be valid and veridical, that is, verifiable via empirical evidence. Nevertheless "they are incompatible"[25]—or in the terms familiar to this study, incommensurable. The authors deal with this troubling incompatibility by developing *two* ontologies, side by side, within the same overriding ontological scaffolding. The following quote highlights the role of this key assumption:

[21]Smith (2005).
[22]Grenon and Smith (2004).
[23]Grenon and Smith (2004).
[24]Grenon and Smith (2004).
[25]Grenon and Smith (2004).

> In order to do justice to the entities of each type, we need to have two distinct ontologies. The ontology adequate for 3-D entities is analogous to a snapshot of the world, it accounts for the entities as they are now. That adequate for 4-D entities is more analogous to a videoscopic view taken upon reality. Basic Formal Ontology (BFO) is the complete and adequate ontology of reality which is divided into the two aforementioned ontologies. More precisely, there is, on the one hand, a succession of ontologies for substances and like 3-D objects, namely, a series of snapshot ontologies of the world at any given instant of time[26].

This distinction is found in several other of the ontologies, and is further pursued in the analysis below.

General Formal Ontology (GFO)

The General Formal Ontology (GFO) is perhaps the easiest of the ontologies to examine in terms of assumptions, which are discussed in section 2.1 of the GFO presentation[27]. The authors initially take a "realist position in philosophy", aware that "there is the need to clarify more precisely the term 'realism'"[28]. However, in terms of the actual *categories* employed (presented in the following section (2.1.1)), they "are conceived in such a way that we are not forced to commit ourselves to realism, conceptualism, or nominalism"[29]. This is yet further complicated by the brief discussion in section 2.1.2, entitled "Existence and Modes of Being". It is worth quoting this section in full:

> In [32] a classification of modes of existence is discussed that is useful for a deeper understanding of entities of several kinds. According to [32] there are—roughly—the following modes of being: absolute, ideal, real, and intentional entities. This classification can be to some extent related to Gracia's approach and to the levels of reality in the spirit of Nicolai Hartmann [29]. But, the theory of Roman Ingarden is not sufficiently elaborated compared with Hartmann's large ontological system. For Ingarden there is the (open) problem, whether material things are real spatio-temporal entities or intentional entities in the sense of the later Husserl. We hold that there is no real opposition between the realistic attitude of Ingarden and the position of the later Husserl, who considers the material things as intentional entities being constructed by a transcendental self. Both views provide valuable insights in the modes of being that can be useful for conceptual modelling purposes[30].

[26] Grenon and Smith (2004).
[27] Herre (2009).
[28] Herre (2009).
[29] Herre (2009).
[30] Herre (2009). Reference [32] in the text refers to *Roman Ingarden. Der Streit um die Existenz*

In contrast with other forms of realism related below, and with the exception of the BFO, this is a realism unusually highly inflected by the phenomenological tradition, established by Husserl, Ingarden, Hartmann and others.

PROTON

Opposed to the BFO and GFO, the PROTON (formerly "BULO") ontology authors employ what may best be described as relativist, constructivist and pragmatist assumptions about the world they set out to model. They happily confess "Its common-sense basis is, of course, quite an arbitrary claim to deal with"[31]. Moreover "the diversity of world knowledge ... actually blur[s] the horizon of hope from a purely philosophical point of view if one wants an ontology that is ... 'compliant' with the common-sense of 'everybody' "[32]. The two pages which discuss the philosophical considerations are somewhat vague about what constitute the "common-sense basis" of the ontology. The discussion presented concerns less the question of assumptions in the sense invoked here (what motivates the categories and distinctions of the ontology) than what might be termed a quasi-philosophical discourse on "logicalized" ontology, existence, essence, meaning and cognition. For example the authors claim "the end users of PROTON are also humans and therefore it is all about everyone's personal cognition and perception of reality"[33]. In fact, as discussed below, the formalisation of the ontology presented in the subsequent fifty or so pages is anything but "arbitrary". The author's conclusion suggests the aim is indeed to describe the "very basic spatial, temporal, material ('physical'), and abstract concepts of world knowledge, which for the most part are independent of a particular problem or domain"[34]. There is little else in the text which suggests what sorts of principles or assumptions might guide the selection of such "concepts".

SUMO

The SUMO ontology is one of the two more widely used upper-level ontologies, and yet it is presented minimal discussion of its assumptions. This is perhaps largely due to the syncretic nature of the ontologies; as the authors characterise its development, "This content included the ontologies available on the Ontolingua server, John Sowa's upper level ontology, the ontologies developed by ITBM-CNR, and various mereotopological theories, among other sources"[35]. The hybridisation of other ontologies suggests that SUMO must in some sense inherit the assumptions of its sources. This becomes a question of methodology, which the authors discuss at some length: "we were faced with the much more difficult task of the 'semantic merge', i.e. combining all of the

der Welt I (Existentialontologie). Max Niemeyer Verlag, T(umlaut)ubingen, 1964; reference [29] refers to Nicolai Hartmann. Der Aufbau der realen Welt. Walter de Gruyter and Co, 1964.

[31] Terziev et al. (2004).

[32] Terziev et al. (2004).

[33] Terziev et al. (2004).

[34] Terziev et al. (2004).

[35] Niles and Pease (2001).

various ontologies into a single, consistent, and comprehensive framework"[36]. The difficulties of reconciling different assumptions are clear from a later section of the paper—again worth citing at length, since it highlights a key distinction which is discussed further below:

> Under the concept of "Physical", we have the disjoint concepts of "Object" and "Process". The existence and nature of the distinction between these two notions was the subject of much heated debate on the SUO mailing list. According to those who adopt a 3D orientation (or "endurantists", as they are sometimes called), there is a basic, categorial distinction between objects and processes. According to those who adopt a 4D orientation (the "perdurantists"), on the other hand, there is no such distinction. The 3D orientation posits that objects, unlike processes, are completely present at any moment of their existence, while a 4D orientation regards everything as a space-time worm (or a slice of such a worm). On the latter view, paradigmatic processes and objects are merely opposite ends of a continuum of spatio-temporal phenomena. The current version of the SUMO embodies a 3D orientation by making "Object" and "Process" disjoint siblings of the parent node "Physical"[37].

This passage echoes in almost identical terms Kuhn's concept of "paradigms", describing the difficulties of assimilating two fundamentally distinct and incompatible "orientations" towards the world. Unlike the BFO, SUMO's authors assume paradigmatic incommensurability presents even co-location of 3D and 4D perspectives.

DOLCE

The DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) ontology devotes several of its 38 pages discussing assumptions. Like the PROTON ontology, it takes what might be termed a "constructivist" stance, in which categories are chosen for their proximation to "cognitive artifacts ultimately depending on human perception, cultural imprints and social conventions (a sort of 'cognitive' metaphysics)"[38]. Moreover the authors of DOLCE confess their ontology is not intended "as a candidate for a 'universal' standard ontology", but rather "has a clear *cognitive bias*, in the sense that it aims at capturing the ontological categories underlying natural language and human commonsense [sic]"[39]. The philosophical antecedents of their approach is motivated in part by the work of Searle, and his notion of "deep background" (Searle, 1983).

The authors also make use of the *endurant[or continuant] /perdurant[or occurrent]* distinction, as well as several other "classical" concepts, which have been part of

[36]Niles and Pease (2001).
[37]Niles and Pease (2001).
[38]Masolo et al. (2002).
[39]Masolo et al. (2002).

philosophical ontology since Aristotle's Categories (Aristotle, 1994). Hence, categories like "universal", "particular", "physical", "abstract", "qualities", "time" and "space" can be located within the upper taxonomic echelons in the ontology[40].

SWIntO—Taxonomising Ontological Assumptions

One effort to make sense of the medley of assumptions made by upper-level or foundational ontologies is represented by the work of Oberle et al. (2007). As part of a broader effort to develop a "demonstrator system which combines intelligent multi-modal and mobile user interface technology with question-answering functionalities over both the open internet and specific thematic domains at the same time"[41], the authors discuss their efforts to construct a hybrid foundational ontology as the basis for subsequent domain-level ontologies. As part of this work, they consider "ontological choices" or "meta-criteria", against which they rate many of the ontologies canvassed here[42]. The "choices" consist of the following distinctions, which briefly paraphrased below:

- *Descriptive vs. Revisionary*—"descriptive" aims to capture intuitionist, "common-sense" categories; "revisionist" aims to describe the "intrinsic nature of the world"[43].
- *Multiplicative vs Reductionist*—"multiplicative" allows for the possibility of multiple, potentially competing ontological points of view; "reductionist" aims to reduce such perspectives to a unifying, single point of view.
- *Possibilism vs Actualism*—"possibilism" allows for possible as well as actual entities (and typically requires some form of modal logical distinction between necessity and possibility); "actualism" admits only actual entities.
- *Endurantism vs Perdurantism*—as previously discussed, "endurantism" considers entities as wholly "in time"; "perdurantism" considers entities as potentially containing temporal parts (and are therefore not "in time", but persist "through time").

The authors present their assessment table 7.4 (redacted here to eliminate other candidate ontologies not surveyed here—OpenCyc and OCHRE, neither represented in OWL)[44].

The authors proceed to develop a hybridised upper-level ontology based on DOLCE and SUMO, *SmartSUMO*[45]—using a similar grafting method to that described by the authors of SUMO itself. I return briefly to this development in the final section below.

[40] Masolo et al. (2002).
[41] Oberle et al. (2007).
[42] Oberle et al. (2007).
[43] Oberle et al. (2007).
[44] Oberle et al. (2007).
[45] Oberle et al. (2007).

Table 7.4: Foundational ontologies and their ontological choices.

Requirement \ Alternative	BFO	DOLCE	SUMO
Descriptive	-	×	×
Multiplicative	-[a]	×	×
Actualism	×	-	unclear
4D	×	×	×

[a]Given the discussion above, it might be argued that the BFO is similarly multiplicative, although it does indeed aim to be "revisionist" in the sense used here.

Extending the Taxonomy

Based on the brief review above, several further salient dimensions can be added to the model for comparison:

- *Derived vs. Original Composition*—SUMO is explicitly derived from several existing ontological sources; the other ontologies appear to be constructed originally, with reference to other systems.
- *Realist vs. Constructivist Attitude*—Both SUMO and DOLCE have some constructs for representing a subjective point-of-view within the ontology itself, suggesting they support a "constructivist" or nominalist standpoint. BFO, by comparison, is stridently realist (though with complications). The GFO leans strongly towards realism also, while the PROTON ontology as best can be divined, also adopts a more constructivist attitude.
- *"Home-grown" vs. Imported Philosophy*—DOLCE explicitly acknowledges the work of John Searle and others as guiding the development of the ontology—and in a general sense can be said to use an "imported" philosophy. The authors of the BFO, at the other extreme, spend considerable time in various publications justifying a "home-grown" take on various philosophical issues. The other ontologies sit somewhere in-between these two extremes.

7.1.4 Structural Features

The most evident structural difference between the ontologies is in size. Table 7.5 compares the number of classes, properties and individuals contained in each of the ontologies.

In terms of modularisation, as indicated the *PROTON* and *DOLCE* ontologies have been constructed as a series of smaller ontologies, which are linked together via the `imports` construct. In contrast the other ontologies are contained within single files.

The *PROTON* has been separated into three separate ontologies: *system*, *top* and *upper*. The *upper* imports the *top* ontology, which in turn imports the *system*

Table 7.5: Ontology Sizes

Ontology[1]	**# of Classes**	**# of Properties**	**# of Concepts**	**Ratio**
BFO	36	0	36	36.00
GFO	78	69	147	1.11
PROTON[2]	266	113	379	2.33
SUMO	630	236	866	2.66
DOLCE[2]	159	280	439	0.57

[a]All figures have been derived by using the OWLAPI library (Horridge et al., 2007) and some custom scripts.
[b]These ontologies are split across a series of physical files, and figures have been collated from all of the files.

ontology.

The DOLCE ontology contains 8 separate subsidiary and interconnected ontologies, yielding a more complex structure:

- `SpatialRelations`
- `TemporalRelations`
- `ExtendedDnS`
- `ModalDescriptions`
- `FunctionalParticipation`
- `InformationObjects`
- `SocialUnits`
- `Plans`

To use the SocialUnits ontology for example means to import the classes and properties from *InformationObjects, ExtendedDnS, TemporalRelations, SpatialRelations* and*DOLCE-Lite* ontologies.

It is also noticeable that the ontologies differ in the degree that they use classes over properties—expressed in the ratio figures above. In the case of DOLCE in particular, this suggests a what might be termed a "functional" or "attributive" approach to the organisation of entities, since the majority of its conceptual constructs are properties rather than classes. This point is elaborated upon further in the discussion of categories below.

7.1.5 Categories

The preceding sections suggest the five upper-level ontologies employ somewhat different methods, assumptions and design strategies; how, then, do they compare in terms of actual categorial or conceptual content? The following sub-section aims to compare only the most abstract, top-level concepts described in the ontologies. Diagrams of the top three or four graph layers (depending upon visual clarity) of the five ontologies were generated using Protégé (Gennari et al., 2003) and the OWLViz plug-in (Horridge, 2005)—these are shown in Appendix A.1. A subset of these graphs are presented for each of the ontologies below, showing the salient classes used in the following discussion.

BFO

```
Entity
 - Continuant
   - IndependentContinuant
   - DependentContinuant
   - SpatialRegion
 - Occurrent
   - ProcessualEntity
   - SpatiotemporalEntity
   - TemporalRegion
```

GFO

```
Entity
 - Item
   - Individual
     - Independent
     - Dependent
     - Abstract
     - Concrete
     - Discrete
     - Continuous
   - Category
 - Set
```

PROTON

```
Entity
 - Object
   - Statement
   - Location
   - Service
   - Agent
   - Product
 - Abstract
   - Language
   - Topic
```

```
   - Number
   - GeneralTerm
   - ContactInformation
 - Happening
   - TimeInterval
   - Event
   - Situation
```

SUMO

```
Entity
 - Physical
   - Process
   - Object
 - Abstract
   - SetOrClass
   - Quantity
   - Attribute
   - Relation
   - Proposition
```

DOLCE

```
particular
 - spatio-temporal-particular
   - endurant
   - quality
   - physical-realization
   - perdurant
 - abstract
   - region
   - proposition
   - set
```

Even this schematic outline shows some initial points of similarity and difference between the five ontologies. In terms of similarity, each starts with a common root concept, “Entity”. The following conceptual distinctions, or near synonyms of them, are also common to at least three of the ontologies:

- *Spatial/Temporal*
- *Abstract/Concrete*
- *Collective/Individual*

- *Continuant/Occurrent* (or, alternatively, *Endurant/Perdurant*)
- *Independent/Dependent*
- *Conceptual/Physical*

These distinctions can be mapped to specific concepts in each of the five ontologies in Appendix A.2.

This comparison demonstrates that there is a high degree of overlap in the use of concepts across the ontology set, and equally, that these concepts are differently configured, so that establishing direct concordances between apparently synonymous concepts is risky. The interpretation of the above distinctions, when applied to particular ontologies, carry considerable ambiguity. For example, the *Conceptual/Physical* distinction aligns `Concept` (GFO), `[GeneralTerm | Topic]` (PROTON) and `Proposition` (SUMO, DOLCE) as all conceptual entities—clearly, however, they are not all synonymous terms. More tenuously, the meaning of *Dependent* might appear to be preserved by the `[Relation | Attribute | Quantity]` (SUMO) and `quality` (DOLCE) classes, since these have equivalently named terms in other ontologies which are sub-classes of kinds of *Dependent* entities: the `DependentContinuant` and `Dependent` classes of BFO and GFO ontologies respectively. The *Continuant/Occurrent* distinction is also difficult to interpret consistently across the ontologies. Broadly, continuant entities are those which "are wholly present (all their parts are present) at any time at which they exist" while occurrent entities "that extend in time and are only partially present for any time at which they exist because some of their temporal parts may be not present"[46]. The GFO ontology synonym for this distinction, the *Continuous/Discrete* pair, nevertheless contains a mixture of both object-like and process-like classes within each of the `Continuous` and `Discrete` super classes—and the ontology also contains a sibling `Presential` class, which appears a more natural synonym for *Continuant.* The BFO ontology subsumes `TemporalRegion` under `Occurrent` and `SpatialRegion` under `Continuant` classes, but also adds `SpatiotemporalRegion` as a subclass of `Occurrent`, with the following extended note:

> An instance of the spatiotemporal region [span:SpatiotemporalRegion] is a part of spacetime. All parts of spacetime are spatiotemporal region [span:SpatiotemporalRegion] entities and only spatiotemporal region [span:SpatiotemporalRegion] entities are parts of spacetime. In particular, neither spatial region [snap:SpatialRegion] entities nor temporal region [span:TemporalRegion] entities are in BFO parts of spacetime. Spacetime is the entire extent of the spatiotemporal universe, a designated individual, which is thus itself a spatiotemporal region [span:SpatiotemporalRegion].

[46] Bazzanella et al. (2008).

> Spacetime is among occurrents the analogous of space among continuant [snap:Continuant] entities[47].

This confirms the point made earlier: two ontological perspectives are supported by the BFO—one sharply distinguishing spatial and temporal, continuant and occurrent entities, the other collapsing within a general occurrent, spatio-temporal conceptual apparatus. Habituation of two fundamental perspectives within the one ontological housing creates a point of dissonance with other ontologies which maintain a single viewpoint, preserving "Continuant" and "Occurrent" entities as primordially distinct and mutually disjoint. The SUMO and DOLCE ontologies are largely consistent in maintaining this distinction, while the PROTON ontology seems idiosyncratically to treat `JobPosition`—arguably a continuous entity—as a kind of `Happening`, while `Service` (in the sense of a service rendered) is a kind of `Object`.

The difficulty of drawing synonymous relations across ontologies is more notable still in a comparison of the summative effect of multiple conceptual distinctions. For example, while each of the ontologies has classes to represent the *Spatial/Temporal* and *Continuant/Occurrent* conceptual pairs, *how* these distinctions are organised differs markedly. The BFO ontology makes a *primary* distinction between `Continuant` and `Occurrent` classes. The distinction between spatial and temporal entities is then a subordinate one—more formally, the pair `[SpatialRegion | TemporalRegion]` is subordinate to the pair `[Continuant/Occurrent]`. The GFO ontology treats these distinctions as *equivalent*—both `[Discrete | Continuous]` and `[Space_time/Space | Space_time/Time]` class pairs are subsumed by the `Entity/Item/Individual` class. The PROTON ontology follows the BFO organisation: the pair `[Object/Location | Happening/TimeInterval]` is subordinate to the `[Object | Happening]` pair. Meanwhile the SUMO ontology has an orthogonal relation between the equivalent pairs: while `Object/Region` is clearly subordinate to `Object`, the nearest temporal synonym, `TimeMeasure`, is treated as a kind of `Quantity`, not a subordinate of `Process`—the nearest SUMO synonym to the `Occurrent` concept used by the BFO. The DOLCE ontology pairs both sets of conceptual classes: the *Continuant/Occurrent* distinction are matched by the near-synonymous pair `[endurant | perdurant]`, while the *Spatial/Temporal* distinction is matched by the `[space-region | temporal-region]` pair of classes. However, the latter pair is subordinate to a higher level class, `abstract`, which is distinguished from the *spatio-temporal-particular* class. Instances of the `spatio-temporal-particular` class (whether members of an `endurant`, `perdurant`, or of another class) are bound to space or time regions via properties, rather than through direct class subsumption relations. This suggests conversion between DOLCE and other ontologies would need to interpret and transform other kinds of relations into class subsumption ones.

Similar complexities can be found in other conceptual overlays. The BFO ontology has no class pair corresponding to the *Abstract/Concrete* distinction, yet syn-

[47] Grenon (2003a).

onymous class pairs are primary distinctions for the PROTON, SUMO and DOLCE ontologies (and a more subordinate distinction for the GFO ontology). Only one of the ontologies, DOLCE, reinforces this conception distinction with a logical constraint: the `abstract` class is declared logically disjoint from `endurant`, `perdurant` and `quality` subclasses of the `spatio-temporal-particular` class, and further annotates the `abstract` class: "The main characteristic of abstract entities is that they do not have spatial nor temporal qualities, and they are not qualities themselves"[48].

The five ontologies also have clear conceptual areas of what might be termed "perspectival specialisation"—areas in which they move beyond upper-level abstractions towards domain-level specificity. The BFO ontology, with 36 classes and no properties, contains only abstract physical classes, roughly representative of the distinctions introduced above (*Continuant/Occurrent*, *Dependent/Independent*, *Collective/Individual*). The emphasis on supporting the mutually exclusive three- and four-dimensional perspectives is the main unusual feature of its categorial structure—although this feature is also supported by DOLCE and SUMO ontologies within a single perspectival view. The GFO ontology uses a number of specialised terms further down the class hierarchy which indicate a scientific or technical orientation: `Chronoid` ("Every chronoid has exactly two extremal and infinitely many inner time boundaries which are equivalently called time-points"), `Topoid` ("connected compacted regions of space"), `Configuroid` ("integrated wholes made up of material structure processes and property processes") and `Situoid` ("processes whose boundaries are situations and which satisfy certain principles of coherence, comprehensibility, and continuity.") are examples[49]. The PROTON ontology contains `Product`, `Service`, `Document`, `JobPosition` and `ContactInformation`, which relate more specifically to organisational or commercial fields[50]. Moreover PROTON makes a first-order distinction between `Entity`, `LexicalResource` and `EntitySource`, suggesting a primary demarcation between entities in the world, and their discursive description and provenance.

The SUMO ontology explicitly incorporates the intentional or constitutive standpoint of an agent—a large number of agent actions, including *Guiding*, *Classifying*, *Listening*, *Looking* and *Meeting*, are subsumed within an *IntentionalProcess* class. These total 114 classes, or 20% of the number of classes in the ontology as a whole, which is suggestive of an internalist or subjectively-oriented perspective towards ontological entities. Finally, the DOLCE ontology largely mirrors the kinds of distinctions maintained by SUMO, but models these as object properties between classes, rather than as class inheritance. Thus it sees entities as bound by mereological and functional, rather than by subsumption relations. This formalist perspective is mirrored by object property names such as `parameterizes`, `postconditions`, `preconditions`, `deputes` and `interprets`. The SUMO ontology has a similarly large number of object properties, but use more colloquial and lay terms such as `causes`, `employs`, `larger`

[48]Gangemi (2006).
[49]Herre (2009).
[50]Terziev et al. (2004).

and `uses`.

Table 7.6 summarises these underlying differences in orientation. These qualitative distinctions could be used to further form the basis of a set of quantitative valuations against the dimensions introduced in the commensurability framework chapter, as well as refinement of what those dimensions, in the case of the five upper-level ontologies, should be; at this stage, it is enough to demonstrate the utility of the kind of interpretative analysis employed here for teasing out what some of the salient distinctions between the ontologies are. The next section examines the sociological context in which these distinctions are voiced and debated, through an online content analysis of two mailing lists. This analysis also brings forward further suggestive extrinsic or social distinctions which mark these ontologies.

Table 7.6: Ontology Orientation Summary

Ontology	**Orientation**
BFO	Minimalist; Supports mutually exclusive 3D/4D physical perspectives; Continuant/Occurrent distinction fundamental; Scientific naturalist epistemology
GFO	Naturalist epistemology; Uses scientific over "folk" terms
PROTON	Focus on commercial/industrial terms; Pragmatic
SUMO	Intentional; Constructivist epistemology; Pragmatic
DOLCE	Constructivist; Scientific; Theoretical; Functional/attributive

7.2 A Dialogical Account of Ontology Engineering

> >I think we're arguing about the definitions of our terms, here. My >use of the term "Truth" causes cognitive dissonance for you.
>
> Well, you haven't actually defined it: but I think I get your drift. It doesn't cause me cognitive dissonance (if it did, I might be more inclined to agree with it): I just think its mistaken[51].

The analysis of the five ontologies suggests that to some degree ontology development takes place in isolated engineering teams, drawing upon disparate sources of inspiration, with different goals and perhaps some level of collegial overlap. In practice, this picture is distorted by the presence of public social media through which researchers openly debate many aspects of ontology design. These represent a fascinating insight of how debate and dialogue around ontologies take place.

[51] Hayes (2007b).

The following sections present a brief analysis of some of the discussion on these lists in relation to upper-level ontologies. The *Semantic Web* and *Ontolog Forum* mailing lists are reviewed in detail, since these include messages from a number of researchers who have worked on the ontologies listed above, or who contribute to the broader academic discussion around formal ontologies. Both lists are publicly available, and anyone can request subscription. In the case of the *Semantic Web* list, subscription is automatic (`http://www.w3.org/Mail/Request`); the *ontolog* forum requires an email request be sent to the forum convenor (`http://ontolog.cim3.net/cgi-bin/wiki.pl?WikiHomePage#nid1J`). The lists have different objectives, and consequently different kinds of communities. The *Semantic Web* list covers all topics related to the Semantic Web, usually with a technological rather than philosophical focus. Subjects include discussion of Semantic Web architecture, terminology, application and specific ontologies, as well as frequent conference announcements and job advertisements. The *ontolog* forum, by comparison, is concentrated on the construction of upper-level ontologies, with considerable reference to both technological and philosophical aspects of this task. Both lists are attended by prominent contributors to academic and practical ontology engineering, and comprise what might be termed "expert communities of practice" in these fields.

7.2.1 Analysis of Mailing Lists

To analyse the lists, a small software script was developed to harvest the contents of emails from their publicly-available archives(W3C, 2010; Yim, 2010). The script retrieved posts since their inception (*Semantic Web*: March 2000; *Ontolog Forum*: May 2002) until May 18, 2009. Mailing list archives typically employ the following structure:

1. Main index page—containing the months the list has been running, with links to posts listed by dates or by thread (subject);
2. Date pages—containing a list of posts for the month, organised by day;
3. Thread pages—containing a list of posts for the month, organised by thread (subject);
4. Individual posts—containing the contents of a single message, including subject, date, author and message contents.

The script exploits this common structure (at least for the two archives in question), and starting with the index page, follows links to the date and message pages automatically. On each of these pages it parses the contents for common elements, such as the date, author, subject and contents of the message. Importantly, message "threads" retain the same subject heading for the most part, permitting analysis of common topics and keywords. The script then captures unique authors, subjects, messages and individual words in a database system. Care has been taken to ensure accuracy in the results, however, for various reasons it is difficult to gain precision with subject, author and word counts—continuous subjects can be arbitrarily varied by authors or their mail clients; authors can post from different mail accounts, with different names or variants; word morphographic variants, aside from plurals, can be difficult to correlate automatically; email thread subject headings can be renamed by correspondents, to follow new "threads" of conversation; and mailing lists can allow for the possibility of "spoofing", faking email contents, due to lack of rigorous authentication methods. The last concern, given the specialised nature of these lists, is a relatively low risk in these particular cases.

7.2.2 Quantitative Analysis

Table 7.7 summarises the number of messages received on both lists by year, based on a survey conducted 19 May, 2009. These figures show a rising interest in both forums in recent years—the *Semantic Web* growing rapidly in 2005, the *Ontolog Forum* in 2007. Total number of messages is comparable, with indications in 2009 that the *Ontolog Forum* is experiencing roughly twice the amount of activity.

Table 7.7: Messages Received By Year

Year	**SemWeb**	**Ontolog**
2000	26	N/A
2001	14	N/A
2002	11	220
2003	29	589
2004	52	577
2005	1,705	517
2006	2,072	619
2007	2,743	3,708
2008	2,962	2,548
2009 (May 18)	965	1,891
Total	10,579	10,669

In terms of distinct author and subject counts, the *Ontolog Forum* exhibits a smaller and more focussed community, as table 7.8 suggests. These numbers indicate each author contributes on average approximately 23 messages across the period surveyed (January 2000 through to May 2009), and each subject receives four messages on the *Ontolog Forum*, compared with approximately eight and two messages respectively for the *Semantic Web* list. This is confirmed by an analysis of the top 20 authors and subjects, which show higher message-to-author and message-to-subject ratios again for the *Ontolog Forum* list.

Although the five ontologies and two comparative studies (OntoMap and SWIntO) analysed above are products of private development, and consequently do not have

Table 7.8: Author and Subject Counts

	SemWeb	**Ontolog**
Total Messages	10,579	10,699
Total Authors	1,361	461
Total Subjects	4,487	2,649
Messages per Author	7.77	23.12
Messages per Subject	2.36	4.04

mailing lists or other public fora, several of the contributing authors featured in both of the lists surveyed. Table 7.9 shows each of the contributors featuring in the lists, along with the number of messages posted.

Table 7.9: Joint Ontology and List Contributors

Author	*Ontology*	*SemWeb*	*Ontolog*
Pierre Grenon	BFO	4	0
Barry Smith	BFO	2	68
Adam Pease	SUMO	0	172
Stefano Borgo	DOLCE	0	3
Aldo Gangemi	DOLCE	13	1
Nicola Guarino	DOLCE	0	1
Alessandro Oltramari	DOLCE	78	0
Marin Dimitrov	OntoMap	1	0
Philipp Cimiano	SWIntO	3	0
Pascal Hitzler	SWIntO	32	0
Daniel Oberle	SWIntO	1	0
Michael Sintek	SWIntO	2	0

These figures can be used as basic heuristics for some of the dimensions introduced for classifying the ontologies above. While over-extrapolation from these figures can be misleading—for instance, other relevant mailing lists are not included here, and there is no means of reviewing offline discussions—based on the characterisation of the lists themselves, it is possible to make several inferences:

1. A contributor to each of the BFO and SUMO ontologies is also actively involved in the *Ontolog Forum* list—suggesting these ontologies have a stronger philosophical orientation;

2. DOLCE contributors were involved in both lists, although only to a minimal degree on the *Ontolog Forum* list—suggesting DOLCE has a stronger technical orientation;

3. No contributor to the GFO or PROTON ontologies participated in either of the lists—suggesting authors of these ontologies are less active in the broader

ontology community, and possibly, that the ontologies themselves experience lower rates of adoption;

4. Contributors to both OntoMap and SWIntO comparisons had some involvement in the *Semantic Web* rather than the *Ontolog Forum* lists—suggesting ontological comparison, even of upper-level ontologies, is regarded as more of a technical than abstract philosophical task.

These tentative observations are corroborated by a word frequency analysis of the ontology terms themselves. Fortuitously, each of the ontologies has an acronym which is unusual enough to make collision with quotidian usage quite unlikely. Table 7.10 shows the number of times each ontology is mentioned, along with their frequency relative to the most commonly cited ontology. Discussion on the *Ontolog Forum* list is predictably far more prolific, given it is dedicated to the establishment of foundational or upper-level ontologies. All of the ontologies are mentioned more often in absolute terms on *Ontolog Forum*, with SUMO, DOLCE and BFO cited more often by a factor of ten or more. Notwithstanding this absolute difference, in relative terms DOLCE is mentioned twice as often on the *Semantic Web* list as SUMO, while SUMO is mentioned nearly three times more often on *Ontolog Forum*. Both GFO and PROTON are mentioned relatively infrequently, reinforcing earlier suggestions that these ontologies have low levels of interest and community engagement.

Table 7.10: Ontology Count

SemWeb	Frequency	Relative Frequency	Ontology	Frequency	Relative Frequency	Ratio
dolce	49	100.0%	sumo	1730	100.0%	35.31
sumo	24	49.0%	dolce	592	34.2%	24.67
bfo	19	38.8%	bfo	176	10.2%	9.26
gfo	13	26.5%	proton	55	3.2%	4.23
proton	6	12.2%	gfo	8	0.5%	1.33

Word Frequency Analysis

A more general word frequency analysis table is shown in Appendix A.3. It displays the top 100 words for both *Semantic Web* and *Ontolog Forum* mailing lists. The frequencies were compiled by counting discrete words in every message across the corpus of each list, and eliminating prepositions, pronouns, common verbs and adjectives, HTML elements and entities (such as `<span>` and `<font>` tags), and certain template words which appeared in every message (such as "unsubscribe"). The entire corpus was converted to lower case during extraction of these statistics. Morphological variants, such as plurals, are have not been controlled for.

Both lists exhibit a large number of common words, 51 out of a possible 100. Terms like "ontology", "semantic", "web", "language", "knowledge" and "information" are clearly of central interest to both communities. However, there are pertinent differences, both in which terms are not common, and in how common terms are ranked. As expected, the *Semantic Web* list has a large number of technical terms, with "rdf", "owl", "uri" and "xml" all featuring in the top twenty results. None of these are in the top twenty results for the *Ontolog Forum* list, with only "rdf" and "owl" appearing in the top hundred (each is mentioned approximately 10% and 25% as often respectively). The *Semantic Web* list also contains a number of terms which relate to possible contexts for discussion and application of the technologies discussed: terms like "workshop", "conference", "systems", "applications", "services", "management", "business" and "social" are either ranked lower or do not appear at all in the *Ontolog Forum* list.

Conversely, *Ontolog Forum* contains many philosophical and mathematical terms which rank highly: "ontology", "time", "language", "logic", "set", "point", "model", "theory" and "world" all appear in the first thirty most frequently used words. Despite the fact that real-world application of ontologies is a frequent topic of debate, these terms indicate a heavy orientation towards abstract and formal discussion. Less perspicuously, three proper names appear in the first forty words—more often than words like "meaning", "list" and "thing" for example—indicating dialogue takes place among a more concentrated group of members. Still less conclusively, many terms refer to the epistemic conditions of the discussion itself—verbs like "leave", "say", "know", "agree", "mean", "take", adjectives like "shared", "real", "true" and "common", and nouns like "context", "discussion", "question" and "view" all suggest a strong tendency towards self-referential discussion *about* the process of discussion on the list. This tendency, however tenuous, does correlate loosely both to the larger average number of posts per subject (*Ontolog Forum*: 4.03; *Semantic Web*: 2.36), and the substantially larger average number of posts per author featured on the *Ontolog Forum* list (*Ontolog Forum*: 23.14; *Semantic Web*: 7.77).

The word frequency analysis shows some significant difference in the nature of the two list communities. But what can be inferred from this to the question of commensurability of the ontologies themselves? At most the results are suggestive:

they show that the SUMO and BFO ontologies have contributors who are active on *Ontolog Forum*, which might suggest they are more oriented towards philosophical rather than technical issues of ontology composition, and more inclined to engage in active debate over these issues with a broader community over time. Potentially these two ontologies themselves are more commensurable also, or at least the differences between them more likely to have been made explicit in the course of discussion on the list. Similarly the kinds of concepts treated in upper-level ontologies—"time", "set", "process", "context", "thing" and so on—receive frequent attention on the *Ontolog Forum* list. Interestingly, many of the pertinent concepts and distinctions used in the five ontologies—such as "entity", "object", "item", "discrete", "abstract", "individual"—do not appear in the top hundred words of either lists. This suggests that neither list is predominantly engaged in trying to determine, for instance, whether the *endurant/perdurant* distinction is foundational or not. Across both lists, considerably greater discussion centers rather around the formal aspects of knowledge representation. In the case of the *Semantic Web* list, these aspects are discussed in preponderantly technical terms: for example, how to construct and connect ontologies using constructs from OWL and RDF language specifications. On the *Ontolog Forum* list, this sort of discussion tends to be considerably more abstract, and is focussed more on general issues of logical syntax and semantics.

7.2.3 Qualitative Analysis

One conversational thread from the *Ontolog Forum* list has been selected for more detailed qualitative analysis. Entitled *Two ontologies that are inconsistent but both needed*, the conversation involves one of the authors of the BFO ontology (Barry Smith), as well as other influential participants—the author of the RDF specification, Pat Hayes; a frequently cited author on ontologies, John Sowa; and a number of contributors to various standards initiatives. Usefully, the subject matter covers both the general problem of commensurability between ontologies, as well as the specific question of interoperability between upper-level ontologies. The conversation takes place in June 2007, some time after the ontologies covered here were developed, so it does not directly relate to the background of their development. Nevertheless it elucidates many of the foundational issues involved in upper-level ontology engineering, which remain active subjects for debate, and brings into view a range of perspectives on the challenges of interoperability between multiple ontologies.

Ontological Dialogue

The discussion in this thread principally involves the problem of reconciling two ontologies with potentially different presuppositions. As such discussions tend to do, it winds over a range of different subjects however, and engages different disputants along the way. Appendix A.4 provides details of the specific turns and twists of the dialogue, with interspersed commentary. Table 7.11 summarises the major movements in the dialogue. The message responsible for the change of topic (within the same subject heading) is indicated, along with a summary of the topic.

Table 7.11: Ontolog forum—Dialogue Map

Message ID	**Date**	**Author**	**Summary**
Preliminaries			
	27–04–2007	Di Maio	Announces invitation for participation in Disaster Management ontology.
54	07–06–2007	Barker	Problem of multiple ontological "perspectives" raised.
59	07–06–2007	Andersen	"Perspectivalism" queried; two options proposed: either ontologies are "incommensurable" or they are not (and "perspectivalism" disappears)
71	08–06–2007	Sowa	Preceding dichotomy queried, perspectivalism re-introduced; granular inconsistencies can dissolve under different perspectival orientations. Issue raised of work involved.
80	08–06–2007	Kusnierczyk	Expresses sympathy with message 59—either ontologies are consistent, or they are not.
81 (?)	08–06–2007	Smith	Offers evidence of logically consistent but philosophically incommensurable ontology (own work).
Perspectives on the Continuant—Occurrent Distinction			
91	08–06–2007	Hayes	Argues for reconciliation of perspectives expressed in Smith's work. Multiple "perspectives" can be reduced, simplified—issue one of terminological rather than ontological difference.
98	08–06–2007	Smith	Pragmatic rebuttal; BFO is successful in practice.
108	08–06–2007	Sowa	Claims informal, lay distinctions are susceptible to critique even when dressed in formal ontological axioms.

Table 7.11: Ontolog forum—Dialogue Map

Message ID	**Date**	**Author**	**Summary**
169	11–06–2007	Smith	Further pragmatic justifications—successful *use* justifies an ontology's design rationale.
?	12–06–2007	Hayes	Reiterates mutual translatability between continuant and occurrent "perspectives".
180	12–06–2007	Smith	Seeming agreement with Hayes' position.
181	12–06–2007	Conklin	Frustration at tenuous discussion, given its initial practical aims—to provide some consensus on whether multiple ontologies can be both consistent, yet reflect different perspectives.
Diversions			
182	12–06–2007	Laskey	Begins discussion on "probabilistic" ontologies; where concept agreement is expressed as "degrees of certitude".
361	18–06–2007	Barkmeyer	Discusses distinctions between ontologies and data models.
Metaphysical Dilemmas			
308	16–06–2007	Partridge	Re-opens debate about continuants/occurrents—suggests distinction depends upon metaphysical perspective rather than empirical evidence.
358	18–06–2007	Hayes	Disputes metaphysical bias; suggests that even upper-level ontologies can be constructed solely out of abstraction from empirical (scientific) observation.
378	19–06–2007	Laskey	Emphasises role of pre-existing cultural bias.
381	18–06–2007	Hayes	Re-affirms value of intuition and observation—rather than metaphysical speculation—as basis for ontology development.
383	19–06–2007	Laskey	Agrees on the value of observational starting points, on pragmatic grounds.

Table 7.11: Ontolog forum—Dialogue Map

Message ID	Date	Author	Summary
409	20–06–2007	Partridge	Parodies Hayes' comments re: metaphysics, by directing criticism instead towards unreflective logicism and empiricism.
411	20–06–2007	Sowa	Points towards continuous "forgetting" of previous development in AI and logic.
417	20–06–2007	Hayes	Emphasises that logic and science, unlike metaphysics, can be measured by demonstrable progress.
432	21–06–2007	Partridge	Critiques this view as being naïvely "positivist"—ignoring essentially Kuhnian "paradigmatic"—and irrational—nature of scientific development.
433	21–06–2007	Hayes	Underscores distinction between progressive science and philosophy mired in "opinion".
Concluding Remarks			
435	21–06–2007	Brown	Questions (similar to message 181) value of the preceding discussion.
448	22–06–2007	Partridge	Affirms need for metaphysical understanding when devising upper-level ontologies for use in large-scale, complex systems.
449	22–06–2007	Hayes	Affirms need to begin with user needs and observation to more abstract concepts ("bottom-up") rather than working down from metaphysical systems ("top-down").
454	23–06–2007	Sowa	Suggests "middle-road"; metaphysical systems can be useful, but only when road-tested against "observation and experiment".

Positions and Distinctions

This thread demonstrates the shifting sands which underpin the building of foundational, upper-level ontologies. The evident tensions between metaphysical speculation, of the kind which have always beset abstract philosophical ontological formulations, and pragmatic engineering concerns—how to construct workable ontologies of the technical kind which facilitate system and data-level interoperability—are drawn out but far from reconciled here. Readings of earlier and later threads, in this forum and others like it, show similar tensions continually emerge. One of the unintended consequences, ironically, of attempting to focus on purely engineering concerns is the inevitable lapse—not always unwelcome, as this thread shows, but invariably protracted and inconclusive—into various forms of metaphysical speculation.

Equally evident are the various postures and positions adopted by those involved in the dialogue. The ontologies surveyed above have the appearance of being effected as a result of some purist intellectual effort, with only a handful of attendant publications describing the process. This debate makes evident, on the other hand, the communicative market-place under which even the most abstract conceptualisations are formulated through the retail practice of what Brandom terms the practice of "giving and asking for reasons". In particular, several crucial distinctions in orientation towards the construction of upper-level ontologies can be drawn. These, in turn, can be applied as dimensions to the assessment of the commensurability of the ontologies themselves.

The first distinction, exhibited throughout the thread, concerns that between pragmatic, empirical, "bottom-up" and metaphysical, speculative, "top-down" approaches to upper-level ontological construction. While the majority of the voices on the list, particularly Hayes and Smith, have a noted aversion to "philosophising" over categories, a minority point to the merit of engaging philosophy as means of avoiding errors in categorial construction. Even Hayes, at one stage, points to the need for some philosophical background:

> Just be aware of a few common mental traps, such as not making the use/mention confusion, and you should do OK[52].

If a consensus emerges at all here, it is that some level of "metaphysics is unavoidable"[53]—the dispute is the degree to which abstract theorising of the philosophical kind is embraced, or alternatively, brought in as a last resort. The distinction hinges on the extent to which upper-level ontology construction is viewed as a purely engineering activity, or whether it is a continuation of a much longer philosophical activity—one in which Aristotle's categories are as relevant as contemporary technical artefacts. Partridge and Sowa, in particular, appear to hold some sympathy with the latter view.

The next distinction is between so-called "3D" and "4D" world views, and whether these are merely verbal transpositions of the same underlying "view". The dispute between Smith and Hayes essentially involves this question. For Hayes, "continuants" are sometimes fortuitous, but always unnecessary ways of speaking about existential

[52] Hayes (2007c).
[53] Hayes (2007c).

phenomena. Smith regards the relationship between “continuants” and “occurrents” as ontologically primary—a view which informs both BFO and DOLCE ontologies.

A further distinction is introduced by the *Probabilistic Ontologies* sub-thread. Here the question is whether existing logical formalisms are sufficient to express degrees of certitude over the claims made in an ontology. Laskey suggests they are necessary refinement to connect machine reasoning, of the “either/or” binary variety, with the kinds of everyday ambiguous reasoning human agents engage in. Sowa cautions that tradition logical expressions can be trivially extended to add modal and veridical meta-claims to ontological axioms. This conversation concerns whether modalities such as necessity and possibility ought to be first-order constructs of the logical formalism in which ontologies are expressed, or rather, treated as axioms of the ontologies themselves. All of the ontologies surveyed above use canonical forms of OWL, and therefore represent necessary and possible modalities as postulated axioms, if at all.

Yet another distinction involves another sub-thread, *Ontology-building vs Data Modelling*, where conventional data modelling is distinguished from ontology engineering. The debate here centres on whether the distinction is one of kind (ontologies being of a different, conceptual order to their physical representation as data models) or of degree (ontologies are simply more refined sub-sets of a general vague category called “data models”).

It is worth noting the thread as a whole arose out of an introduction to participate in the development of a disaster management ontology. At least several participants express some frustration that the meandering threads never tie back to the originating subject, and note the difficulty of ever arriving at consensus over deep philosophical issues, while practical issues of (lower-level) ontology engineering remain. A further distinction can be introduced to capture these positions—about whether there is a need for upper-level ontologies at all.

In terms of the possibility of originating question—“how to reconcile two potentially inconsistent ontologies”, which can be transposed into the terms of this study as the question of commensurability—again several distinct positions can be identified. Hayes argues, at least for the “potentially inconsistent” examples given, that this is a purely terminological issue, one in which one set of axioms can be re-written into another trivially—at the cost of some effort, but without sacrificing integrity or consistency. Smith, at least in relation to the “3D/4D”, argues for an essentially “incommensurable” thesis—two inconsistent viewpoints can, however, be housed within the one ontological scaffold. Laskey and Sowa both argue that commensurability is a question of degree rather than kind (with Laskey further insisting that probabilistic ontologies can best represent such degrees)[54]. Partridge suggests that a common metaphysical foundation is essential—otherwise there is no means for establishing commensurability at the level of domain ontologies. The value of an upper-level on-

[54]As it happens, these authors share the point of view adopted in this study as well.

tology is therefore not its purely veridical status, but its usefulness as a means for making explicit what underlying assumptions those domain ontologies make. Hayes' response echoes obliquely the findings of the survey above—that the push for resolution at an "upper-level" makes for further questions and yet further speculative "levels".

In addition to explicit positions adopted, there are implicit differences in how members of the list engage. While it is an "expert" community, some members are more conciliatory to opposing positions than others. Where Hayes, Partridge and Smith—along with many others who post less verbosely and frequently—often happily engage in point-scoring, Sowa, in particular, generally adopts a strategy of qualified agreement, where the qualification attempts to extend a line of thought or embrace other contrary positions. For example, out of nearly a thousand messages posted to the forum over the period surveyed by Sowa (nearly ten percent of the total number of messages posted), 264, or more than a quarter, include the exact construction "I agree". Elsewhere, authors use familiar tropes of informal online communication: irony, parody, questions (both rhetorical and intentional), long interleaving responses and brief, dismissive rebuttals, exasperated summaries and erstwhile explanation. The performative flavour of individual contributions, and of the community as a whole, can be used to characterise particular ontological efforts, however tangentially—they are suggestive, at least, of the motivations, orientations and intentions under which such technological artefacts are produced. Directly, in this instance, Barry Smith's tone conveys a sense of hard ontological commitment to the categories posited in BFO; indirectly, the forum provides a sense of the "behind-the-scenes" gerrymandering required to build consensus around ontologies, particularly those which are not subject to established disciplinary or community practices.

These distinctions can be summarised in the following set of dimensions of specific relevance to the ontologies in this study:

- Role of metaphysics in ontology engineering: essential or accidental?
- "3D/4D" distinction: ontological or terminological?
- Possible and necessary modalities: require first-order support in the formalism?
- Ontologies and data models: different in degree or in kind?
- Upper-level ontologies necessary?
- Commensurability: multiple, potentially inconsistent viewpoints supported?
- Viewpoint: negotiable or resolute?

With some modest adaptations, these in turn can be applied as interpretive dimensions to the surveyed ontologies as part of a general evaluation of their commensurability. The evaluation of the ontologies against these dimensions is presented in the concluding section below.

7.3 Conclusions: Assessing Commensurability

This analysis concludes with two sets of findings: one outlining what can be said about the commensurability of upper-level ontologies on the basis of the analysis above, the other reflecting on what the analysis might mean for a general theory of commensurability, based on the framework which has been applied.

7.3.1 Commensurability of Upper-Level Ontologies

The exploration of the five "upper-level" ontologies has suggested considerable areas of both similarity and difference. Structurally, the PROTON and DOLCE ontologies show greater modularisation, while PROTON, DOLCE and SUMO are considerable larger and semantically denser than GFO and BFO. The DOLCE ontology also favours use of object properties to relate entities functionally, rather than via class subsumption relations. This is carried over in the more scientific and theoretical orientation of DOLCE, evidenced by use of specialised terminology, a feature it shares with GFO, and to some extent with BFO. Comparatively, the PROTON and SUMO ontologies share a more pragmatic and vernacular orientation. The BFO, SUMO and DOLCE also permit multiple perspectives on physical entities—they can be described using spacetime coordinates (4D), or with clearly demarcated spatial and temporal characteristics (3D), along a more abstract distinction between "Continuant" and "Occurrent" categories. This is evident in the BFO ontology directly, but requires some reference to the surrounding literature for SUMO and DOLCE. It is unclear how the GFO and PROTON ontologies are positioned around this distinction, but since both support some variant of the "Continuant/Occurrent" distinction, it can be assumed they operate within a three-dimensional paradigm. The SUMO ontology, and to a much lesser degree the PROTON and DOLCE ontologies, also explicitly model an agent's intentional relation to entities in the world, permitting—though not necessarily insisting upon—a constructivist rather than naturalist outlook. Despite considerable overlap, conceptual *equivalence*, or synonymy, is frequently hard to establish, due to differing levels of terminological intersection, use of functional roles over class subsumption (in the case of DOLCE), greater conceptual density with the larger ontologies (in the cases of PROTON, SUMO, DOLCE), and a general lack of transparent isomorphisms between the conceptual graphs of the ontologies.

Table 7.12 summarises some of the findings, using a combination of the dimensions introduced in the general model in Chapter 5, and those which have presented themselves in the course of the analysis of upper-level ontologies particularly. In addition, I have added the SWIntO variables ((Oberle et al., 2007)) as supplementary dimensions, since these are largely specific to the upper-level ontologies described, and are not included in my general taxonomy. Valuations for each of the ontologies are relative—a low valuation on the "Small vs. Large" dimension, for example, indicates a small number of logical axioms relative to the other ontologies considered. "Low" and "High" values reflect evaluations against the second term of each conceptual opposition expressed by a dimension.

Table 7.12: Ontology Commensurability Matrix

Dimension	**BFO**	**GFO**	**PROTON**	**SUMO**	**DOLCE**
Structure—How are the ontologies structured?					
Small vs. Large	Low	Low	Low	High	High
Light vs. Dense	Low	Low	Moderate	High	Moderate
Classificatory vs. Attributive	Low	Moderate	Moderate	Moderate	High
Low vs. High Modularisation	Low	Low	Moderate	Moderate	High
Semantics—How do the ontologies relate to "real-world" objects?					
Possibilism vs Actualism[a]	High	Unknown	Unknown	Unknown	Low
Simple—Complex	Low	Moderate	Low	High	High
Subject—What sorts of objects do the ontologies describe?					
Concrete vs. Abstract Objects	High	Moderate	Low	Moderate	High
Natural vs. Social Objects	Low	Low	High	Moderate	Low
Style—How are the ontologies authored?					
Normative vs. Descriptive	Low	Moderate	Moderate	High	Moderate
Tentative vs. Committed	High	Moderate	Low	Moderate	High
Process—How are the ontologies developed?					
Derived vs. Original Composition	High	Moderate	Moderate	Moderate	Low
"Home-grown" vs. Imported Philosophy	High	Moderate	Moderate	Moderate	Low
Implicit vs. Explicit Assumptions	High	Low	Low	High	Moderate
Ad Hoc vs. Rigorous Design Methods	Moderate	Moderate	Low	High	Moderate
Practice—How the ontologies are used?					
Low vs. High Recognition	Low	Low	Low	High	High

Table 7.12: Ontology Commensurability Matrix

Dimension	BFO	GFO	PROTON	SUMO	DOLCE
Low vs. High Usage	Moderate	Low	Low	High	High
Purpose—What motivates the development of the ontologies?					
Low vs. High Economic Motivation	Moderate	Low	High	Low	Low
Low vs. High Scientific Motivation	High	High	Low	Moderate	High
Perspective—What perspective "informs" the ontology?					
Realist vs. Constructivist Attitude	Low	Low	Moderate	High	High
Descriptive vs. Revisionary[a]	High	Unknown	Unknown	Low	Low
Multiplicative vs Reductionist[a]	Moderate	Unknown	Unknown	Low	Low
Endurantism vs Perdurantism[a]	High	Low	Low	High	High
Essential role of metaphysics[b]	Moderate	Unknown	Low	High	Moderate
Importance of "3D/4D" distinction[b]	High	Unknown	Unknown	Low	Moderate
Modalities supported[b]	Moderate	Low	Low	High	High
Ontologies vs data models[b]	High	Moderate	Low	Moderate	Moderate
Necessity of upper-level agreement[b]	High	High	High	High	High
Multiple viewpoints	High	Low	Low	High	Moderate
Negotiable viewpoint	Low	Moderate	Moderate	Moderate	Moderate

From this matrix several patterns emerge. SUMO and DOLCE ontologies match up on a number of dimensions, and do not differ greatly on any. That they are broadly

[a] Taken from the SWIntO analysis (Oberle et al., 2007).

[b] These dimensions are derived from the mailing list analysis above. See discussion below for some important caveats about their application to ontologies directly.

commensurable is further bourn out in efforts to develop translations between them (Oberle et al., 2007). However, their relative size and complexity would suggest a large number of "local" commensurability issues, at particular branches of their respective taxonomic structures. BFO seems to differ markedly from both of these, and indeed from the aims of PROTON as well. Since it is similarly designed for use in scientific and biological systems, it is perhaps unsurprising that the GFO ontology is closest, at least for dimensions where values can be meaningfully derived. Otherwise, the GFO and PROTON ontologies stand out as relatively idiosyncratic in terms of usage and available documentation—relatively little more can be inferred from the sources available. A large number of "Unknowns" for these ontologies might imply either better commensurability—or more likely, since they leave open large degrees of interpretative scope for different domain ontologies importing them, might imply "hidden" pockets of potential incommensurability which might emerge only on further analysis. By contrast, the explicitness attached to BFO, SUMO and DOLCE ontologies suggests areas of incommensurability are easier to locate up front.

While the mailing list analysis can be used to generate a series of evaluations of the ontologies themselves, this kind of exercise is perhaps more helpful for considering the question of commensurability of upper-level ontologies generally. In particular, the distinctions raised at the end of the analysis are perhaps questions more to be asked of the situational context in which upper-level ontologies are being considered. In some situations, it might be useful to ask whether there are metaphysical issues important for the users, systems and requirements at hand; whether different systems must agree on their definition of abstract concepts; whether multiple viewpoints can be accommodated; and whether differences in viewpoints can be negotiated, and if so, how? In other situations, where an analyst needs to evaluate upper-level ontologies, the dimensions and distinctions outlined above could become a series of evaluative criteria. Here it might be useful to ask what it would mean to view the world as ontologically divided into objects and processes, or on the other hand, to see all things as possessing both "object-like" and "process-like" features in different measures—or, *pace* Smith, to ask whether both viewpoints can be housed in a single, logically consistent but philosophically incommensurable system. A further question might query whether, from a procedural point of view, these kinds of distinctions ought to arise organically, through piece-meal observation and analysis, or alternatively, ought to be imposed as a set of guiding metaphysical assumptions from above. And, finally, it might be asked what kinds of downstream commensurability issues arise by the assumptions made by upper-level ontologies, and the lower-level domain ontologies they are designed to support. In short, these questions could be more useful as a broader interpretive "framings" for consideration of other, more fine-grained commensurability dimensions, such as whether the ontologies employ similar design methods. Consequently, while these dimensions are included under the "Perspective" group above, they better reflect general aspects of the situation in which the ontologies are considered, rather than the ontologies themselves. This point is revisited briefly in the "Implications" section below.

7.3.2 Implications for a General Theory of Commensurability

What do these findings suggest for a theory of commensurability? As indicated in Chapter 5, commensurability is assessed against a contextual backdrop of a given scenario—typically, a project with requirements, aims and purposes. Since the development of upper-level ontologies is what might be described as a niche market—particularly relative to the wide levels of use of document formats, the subject of the next chapter—it is hard to characterise the sociological environment in which these ontologies are developed and used. However, the quantitative and qualitative analysis of two mailing lists— featuring some of the ontology contributors and many other developers and users of ontologies—are revealing. On the one hand, comparatively little discussion takes place over the actual categories of upper-level ontologies, in spite of the avowed purpose of the lists. On the other, the lists do discuss questions of mechanics—how to develop and deploy ontologies—as well as questions of logical entailment within and between ontologies. The *Semantic Web* list is on the whole dedicated to both the technological and operational side of ontologies—announcements about conferences, workshops, specification releases, and so on— while the *Ontolog Forum* list focusses more on issues of ontology content, but nonetheless features many discussions around broadly logical and methodological issues, rather than those of substantive ontological content. As the thread described above shows, this coverage includes the very problem of ontology commensurability itself.

The lists proved useful as heuristic aids for understanding the general backdrop against which the surveyed ontologies can be understood. One immediate result is that what appear to be posited categories within those ontologies are still very much the subject of considerable contention. Further, what appear to be circumstantial deviations between ontologies—fortuitous reliance upon one distinction over another—can be shown to be rooted in fundamental philosophical positions, which are not clearly evident in either the ontologies themselves, or their supporting literature. How vital differences in these positions are again is a matter for context—but clearly, in the case of BFO ontology, one of the key authors holds a resolute view as to the primacy of the top-level categories posited. Drafting connections from BFO to other ontologies based on purely lexical considerations is likely to obscure at least the authorial intent, if not the actual extension of these categories to other domain-level ontologies in practice. How much adoption of an upper-level ontology implies a wholesale commitment to its claims is yet a further question, bearing here on the commensurability relation between importing domain-level and imported upper-level ontology. Concern over this question has, in turn, led some members of these lists to advocate either forms of ontological pluralism—in which multiple, incompatible conceptual schemes are happily co-opted—or abnegation—where talk of "upper levels" are ignored altogether. Each of these options implies some weaker form of interoperability, where total agreement is passed over in favour of partial and local—but perhaps workable—agreements.

Practically, the absence of direct background material about the ontologies themselves led me to examine two mailing lists where the peculiar fusion of speculative philosophical and detailed technical subjects are discussed. This suggests, firstly, that a range of approaches and data sources need to be considered when looking for commensurability "clues". Another consequence of this analysis was the addition of several further distinguishing dimensions to the commensurability evaluation model. However, these dimensions could relate better to the situational context in which commensurability is evaluated, rather than to the ontologies themselves—and suggests that, in terms of the commensurability model outlined in Chapter 5, it may be important to model the context more stringently. In practice, the vagueness and open-endedness of "context" make such a formal treatment a difficult prospect—despite some existing efforts to do this. I return to this subject in the conclusion to the study, as a candidate area for further refinements and research of the model.

While the upper-level ontologies surveyed demonstrate impressive theoretical coherence, engaging with the public fora in which they are produced shows that for many questions of fundamental ontological importance—in both philosophical and engineering senses—no kind of Platonic-level resolution is in sight. Rather the mailing lists evoke an atmosphere of interminable dialogue, intractable positions and an endless recasting of distinctions. Nevertheless, engagement with these social networks provides a necessary warning against any superficial reconciliations between concepts which a purely technical review of ontologies might suggest. It indicates the question of commensurability itself is enmeshed within the messy retail world of discursive practices. The next chapter, covering efforts to standardise document formats, demonstrates just how much retailing can take place in the effort to produce standards of supposedly pure technical formats, models and specifications.

Chapter 8

Case Study: Document Formats

> 'Henceforth, my dear philosophers, let us be on guard against the dangerous old conceptual fiction that posited a "pure, will-less, painless, timeless knowing subject"; let us guard against the snares of such contradictory concepts as "pure reason", "absolute spirituality", "knowledge in itself": these always demand that we should think of an eye that is completely unimaginable, an eye turned in no particular direction, in which the active and interpreting forces, through which alone seeing becomes seeing something, are supposed to be lacking; these always demand of the eye an absurdity and a nonsense. There is only a perspective seeing, only a perspective "knowing"; and the more affects we allow to speak about one thing, the more eyes, different eyes, we use to observe one thing, the more compete will our "concepts" of this thing, our "objectivity", be' (Bourdieu, 1990, quoting Nietzche).

This study seeks to examine the commensurability of document formats, with a particular focus on the recent controversy over the question of document format standardisation. At first glance, this is a peculiar choice of study, since document formats are not technically ontologies at all, in the terms outlined by the Semantic Web (Bechhofer et al., 2004). Indeed, the largely unstructured nature of documents makes them poor choices for definition as an ontology. Recent efforts to describe document formats more formally require some revision to this picture, however. Firstly, the idea of a "format" implies at least some level of structuration. Secondly, the *lingua franca* of contemporary document formats is XML (eXtended Mark-up Language); and it also provides the canonical syntax in which ontology-like definitions are expressed. Thirdly, there has been some effort towards an inverse move—embedding or extracting the facts of an ontology contained within documents (RDFa (Birbeck and Adida, 2008) and GRDDL (Davis and Halpin, 2007) are two such examples). It is not therefore unreasonable to consider the structure and metadata of documents as themselves representing a series of facts expressible in a formal ontology. Finally, and of greatest significance here, document formats embed precisely the kinds of background assumptions of formal systems which have been considered in the overall study so far.

What motivates the selection of document formats in particular—in contrast to ontologies or schemas from some other field—is the (for this argument at any rate) timely and fortuitous presence of a controversy around format standardisation, which brings to light political, economic, legal and cultural dimensions of the question of commensurability. The controversy concerns the standardisation of Office Open XML (OOXML), a proposal put forward by the Ecma International standards consortium to the International Organisation for Standardization (ISO) in December 2006 as ISO/IEC DIS (Draft International Standard) 29500. OOXML has been largely developed and promoted by Microsoft, a member of Ecma International. The process of standardisation is controversial due to the presence of another rival document format, OpenDocument Format (ODF), which only recently was also ratified by ISO (as ISO/IEC 26300). This format is strikingly similar in aims, if not in detail; it was largely sponsored by Microsoft competitors, Sun Microsystems and IBM.

This controversy has brought forth an unprecedented amount of press and commentary, much of it publicly available via online media, blogs and mailing lists. As the authors of a comparative report on the two formats suggest, in exuberant tones:

> The software industry has rarely seen debates as intense as those surrounding OpenDocument Format (ODF) and Office Open XML . . . during recent years. It's a story that has many elements appropriate for a James Bond movie, with multibillion dollar business empires at risk, global political intrigue, and even some conspiracy theories at the interaction of capitalism (commercial software products), democracy (industry standards), and communism (e.g., related standards controlled by the People's Republic of China). This is improbably heady stuff for what's ultimately a debate about something as mundane as file formats (O'Kelly and Creese, 2008)[1].

The public nature of the debate, as well as the international scope of the standardisation process, provide a more visible and relevant context for examination than most discussions around ontologies, which tend to be embedded within relatively small professional communities. Aside from the prurient interest, many of what might normally be implicit assumptions about the formats become explicit in this debate via the avenues of public dialogue and discourse. This case study departs from the previous one on upper-level ontologies, which was to a large extent an intrinsic technical analysis of upper-level ontologies, and only to a lesser degree an extrinsic social analysis of the communities who develop them. The current study focusses on both in roughly equal measure. Only through such an examination can some of the more complex dimensions of the question of commensurability be brought into the open.

[1]Ironically, the report's authors themselves were to become embroiled in part of the controversy (see the *Sociological Analysis* below).

The study begins with an outline of the background of the controversy, including a brief history of document formats in the electronic era. Given the enormous scope of the specifications underwriting the formats, the technical analysis examines some key points of difference, rather than attempt an exhaustive comparison. The sociological analysis, in turn, uses the language of game theory to describe the sequence of events in the controversy—a decision prompted in part because the language of game theory is itself embedded in much of the discourse of the participants. A formal game theoretic model is not developed here however; rather the purpose is to demonstrate how, in this instance, a broader view of social context can inform the practical question of document format interoperability. Towards this end, the commensurability framework developed earlier is applied to both technical and sociological dimensions. The findings are then summarised, and the framework is evaluated in terms of how well it facilitates the assessment of commensurability in this particular case. Such pay-offs ought to be useful both to engineers engaged in document conversion, and policy makers reflecting on document management policy.

A preliminary note: the treatment here oscillates between consideration of documents specifically as the products of word-processing software (such as *Microsoft Word*), and more generally, as the products of office suite software (such as *Microsoft Office*). The two formats considered here cover word-processing, spreadsheet and presentation documents, as well as subsidiary document objects, such as charts, graphs, tables and so on. However, for reasons of space and convenience the analysis often focusses only on word-processing kinds of documents. It should be clear from the context which kind of document is being discussed—in the absence of indicators, it is used in the general sense as outputs of office productivity software (including word-processor software).

8.1 A Brief History of Document Formats

What is a document? Occasionally the semantic questions generally left to lexicographers and linguists take on vastly greater economic and political dimensions. In 2005 the State of Massachusetts made a decision that all documents created and archived by the state must be based on open formats[2]. This decision caused a simmering debate on document formats to erupt into the public domain. Until now a largely arcane technical dispute had been conducted over the choice between a format proposed by Ecma International, largely sponsored by Microsoft, and another format proposed by OASIS (Organization for the Advancement of Structured Information Standards). On the one hand, Microsoft documents had been *de facto* standards for at least the previous decade and a half, as competition gradually petered out of the office software market in the 1990s. On the other, due in no small part to the enthusiastic enter-

[2] Commonwealth of Massachusetts (2005). Note that as with the other studies, sources treated as primary are cited as footnotes rather than inline.

prise of several of key Microsoft competitors (most notably, Sun Microsystems, IBM and Novell Corporation), a new document format called the OpenDocument Format (or ODF) had been attracting attention as a possible alternative. On May 1, 2005, ODF had been submitted to ISO (International Organisation for Standardisation) / IEC (International Electrotechnical Commission)[3], and had been subsequently ratified under the name of *ISO/IEC 26300:2006* in 2006[4]. This set the scene for the State of Massachusetts policy statement, which acted as a catalyst for wide-ranging governmental and organisational reviews of document standards around the world.

The case of the State of Massachusetts itself is a complex one, and worthy of study in its own right. The initial decision to adopt ODF as the standard for documents within the State quickly became embroiled in political debate, which saw the resignation of the policy's key architects, Erich Kriss and Peter Quinn (respectively, the state's Administration and Finance Secretary, and CIO) in late 2005[5]. Subsequently the state's strong stance on ODF was ameliorated to include the emerging Microsoft standard, OOXML (Office Open XML) in 2007[6]. Instead of being written off as yet another failed government IT initiative, the case prompted significant interest in a variety of media channels. The "blogosphere" was to become an especially important outlet, one through which opinion, commentary and technical analysis increasingly were voiced, as both proponents of ODF and OOXML sought to analyse and indeed influence governmental policy outcomes[7]. In the broader, global dimensions on the subsequent debate over the standardisation of OOXML, the rapid rate of often volatile discussion on blogs and other online forums proved to be a fascinating counterpoint to the slow-moving diplomatic discourse echoed through the bureaucratic channels of august standards bodies. Before venturing into the wilderness of that debate, however, it pays to look further at the recent history of document formats, to understand why the question of commensurability between duplicated standards ought to arise at all.

8.1.1 Whys and Wherefores of Document Formats

Electronic documents are one of the cornerstones upon which the computing era has been founded. They represent the convergence of two mid-twentieth century innovations: xerography and electronic computers. Efforts to standardise upon the formats of electronic documents betray nearly as long a history. The first standardised character set, ASCII (American Standard Code for Information Interchange), was approved by the American National Standards Institute (ANSI) in 1963 (Brandel, 1999; Jennings, 2004). A subsequent iteration was released in 1967 by the Ecma group—a consortium body that also plays a central role in the current document

[3]Wikipedia (2008b).
[4]ISO (2008a).
[5]Shah et al. (2007).
[6]Pepoli and Dormtzer (2007).
[7]Updegrove (2007a); Mahugh (2007).

formats debate. ECMA-6, the current version, is spelled out in a terse 28-page document[8]. However, this conciseness belies the heated debate that took place during the development of ASCII—a debate prescient of contemporary battles over standards development. IBM, already an entrenched leader in the fledgling computer industry, completely by-passed ASCII in favour of a rival character set, EBCDIC (van Wingen, 1999).

In the 1970s, a number of approaches were undertaken to specify standardised document structures composed of more coarse lexical units than character sets. Two of these formats are briefly discussed here, since they indicate two contrasting approaches to document formatting which resonate in more contemporary debates. SGML (Standard General Markup Language) was developed out of an earlier General Markup Language (GML), developed by IBM as part of a publishing system called the Document Composition Facility[9]. SGML was designed to give precise meaning to the structure of documents, while separating out instructions for rendering or presenting those documents[10]. SGML arose out of several simultaneous projects in both academia and industry in the late 1960s and early 1970s. In response to problems of machine hardware interoperability, Charles Goldfarb, an IBM employee, proposed a method of partially automating what in today's terms would be described as "supply chain integration" in the publishing industry. The result was a mark-up language and environment that could integrate "publishing and information retrieval activities"[11]. IBM contributed much of the research and development required to make SGML both an operable working environment and a standardised document mark-up language; this led, in turn, to its success in large publishing and document management environments in the 1980s[12]. The role of market-dominant companies steering standardisation efforts is a theme which reappears in the content of the current debate, and IBM was early to recognise the commercial advantages in doing so. However, complexity of SGML itself, coupled with the then still nascent era of personal computing, ensured it remained in the terrain of heavy industry, where there existed the human and machine resources capable of processing it. It nevertheless was the progenitor of two later mark-up languages of considerably greater consequence: HTML and XML.

TeX(and later, LaTeX) was developed purely as a typesetting language in the late 1970s. Its goal was orthogonal to SGML; it was both more oriented towards specifically textual mark-up, and more ambitious in terms of representing typography at a high level of fidelity. It was designed by Donald Knuth, a highly respected computer science academic, in response to the poor drafting and typesetting of his own book, *The Art of Computer Programming*[13]. It became gradually widespread within

[8]Ecma International (1991).
[9]IBM Corporation (1980, 1991).
[10]Ditch (2007).
[11]Goldfarb (1973).
[12]Goldfarb (1996).
[13]The CTAN team (2008).

academic publishing, particularly in the mathematical and scientific communities, as it provided a mechanism for rendering complex notations typographically[14]. Outside of this community, however, uptake has been relatively low, again due to the technical complexity of the syntax. TeXwas a purpose-built format, designed to provide highly detailed instructions to software on how to layout a document for printing—it thus provided considerable semantic specificity. SGML, on the other hand, provided the syntactic structure for documents, as well as the general means for specifying the semantics—however authors themselves had to supply the actual semantic definitions. Aspects of *both* of these approaches come to be used in present-day document formats like ODF and OOXML.

Both SGML and LaTeX, then, are early examples of highly structured document formats, adopted as *de jure* and *de facto* standards within the relatively niche industries of industrial and scientific publishing. Both formats were stored in humanly-readable ASCII text form. While this complicated textual composition for non-technical users, it allowed programmers from different companies and organisations to read and write document expressed in them. As developers of the World Wide Web, using HTML, were to come to know by the 1990s, this was a vital property for the development of many kinds of textual processing tools and systems—document editors, browsers, search engines, cataloguing and content management systems, and more. However, human legibility (albeit legibility by those with proficient technical skill) was a feature that was soon to be lost among document formats in the world of word-processing and office suites, which up until the present controversy utilised exclusively binary formats, for the best part technically opaque and heavily protected as company intellectual property. Nevertheless, in the same period, several other, more specialised formats also emerged: *troff* and *nroff* for typesetting, Postscript and PDF for printing, and TEI and Docbook for structured mark-up[15].

The early period of computing witnessed, then, the development of many key elements of the modern electronic document: character encoding, formats, mark-up languages and typesetting systems. Broader computing developments included features necessary for document transmission: fonts, image formats, printer technology and communication networks. Soon after, these technologies were to move beyond the specialised fields of industrial publishing, and become ubiquitous through their dissemination on personal computers. Already some of what were to become common problems of technical standardisation had emerged: companies which filled a key role in technological innovation also had vested interests either to ignore (in the case of EBCDIC) or promote actively (as with SGML) various standardisation efforts. The involvement of corporate actors in the contrary movements towards both standardisation and differentiation of technical data formats becomes considerably more complex in the case of the current controversy. In anticipation of some of the themes treated

[14]The CTAN team (2008).

[15]A recent survey of document formats highlights the differences between these formats in some detail (Wilkinson et al., 1998).

further on below, it is worth also noting the longevity of some of these formats—SGML and LaTeXcontinue to be widely used in their respective niche markets up until the present day.

8.1.2 The Resistible Rise of *Microsoft Office*

In the 1980s a new sub-revolution was under way—the rise of the personal computer. Document composition was one of the key tasks demanded of it, and the kinds of technical standards available—ASCII, SGML, LaTeX—were too limited or too challenging for the new possessors of these machines, the home computer enthusiast or office knowledge worker. Thus word-processing and spreadsheet software became a lucrative market for newcomer companies like Lotus, and semi-incumbents like Microsoft (founded in 1975). These applications stored data in binary formats, unreadable and usually undocumented (since the format represented an important piece of a software vendor's intellectual property). The first version of *Microsoft Word* was developed in 1982 under the name "Multi-Tool Word" (Allan, 2001); it was preceded by some years with the launch of *WordPerfect* in 1979 (Mendelson, 2009). The first version of Microsoft Excel was released under the name "Multiplan" in 1981, although it too was quickly eclipsed by the success of *Lotus 1-2-3* (Allan, 2001). For much of the 1980s, and beyond, Microsoft engaged in the kind of corporate struggle symptomatic of the IT industry: on the one hand, and at all costs, it needed to win new customers in new software markets; on the other, as an operating system vendor, it needed also to ensure some level of interoperability and compatibility with its office software competitors, since it had to support the emerging ecosystem of software development on it platform. Moreover, alongside other vendors it had to contend user complaints about the difficulties of opening, reading, editing and saving documents created in different tools. Hence the question of commensurability was important even in the earliest days of commercial word-processor software development. Naturally, it was not a question asked in abstract terms of commensurability, paradigms, epistemologies and ontologies; it was asked rather in terms of a new set of information technology criteria and desiderata: compatibility, formats, performance and competing features. Equally a new vocabulary emerged to describe the electronic workplace. Terms like "document incompatibility", "file conversion", "software versions", "binary formats", "printer errors", "help systems", "invalid characters", "vendor lock-in" and "feature creep" infiltrated the general professional lexicon. Where previously they had been the obscure domain of IT technicians and engineers, by the 1990s these terms, and the problems they directed attention towards, became endemic to virtually every office environment. What motivated the rise of this new vocabulary? In particular, just how can documents be "incompatible"?

Word-processor software systems facilitated in one sense the democratisation of electronic documents from the highly structured, yet obscure document formats that preceded them. Their main purpose was to simplify the entry of text into a file, for printing, archiving and sharing. The sorts of features that demarcate a document from any kind of written or graphical information had to be faithfully replicated in their electronic forms. Electronic document formats thus had to support a long list of existing textual conventions: margins, spacing, alignment, emphatic marks, hyphenation and pagination, lists, tables, headings, fonts, international characters, graphical elements, bibliographies, indexes and tables of contents, footnotes and endnotes, header and footer information, comments and annotations. Soon they also needed to support a host of new features and functions specific to the electronic era—hyperlinks, video and audio, forms, programmable events, change tracking, versioning, fax, email and real-time collaboration. Yet there were, during the incipient years of word-processor development, no governing bodies declaring which of these features were necessary, nor in what order they must be implemented. In typical capitalist fashion, the market declared what it wanted, and software vendors responded as best they could. Small wonder then that differences arose between software programs, and even between versions of these programs. What with hindsight appears poor planning was more likely a justified response to market demand, alongside fierce competitive pressure to be "first to market". To a large extent compatibility itself arose as an issue companies needed to support as they would any other feature—it was the market that demanded this too. At this point vendors were faced with the dilemma mentioned earlier—how to differentiate product features in order to gain a competitive advantage, and yet provide as one of these features compatibility with other products? This dilemma returns in a revised form in the current debate between the latest Microsoft format (OOXML) and the OpenDocument Format (ODF).

Allan (2001) writes of the early word-processor market:

> At the end of the 1980s the two leading word processor programs were *WordPerfect* and the different versions of *Microsoft Word*. *WordPerfect* was in the number one position. However with the Macintosh application included, *Microsoft Word* was closing the gap.

By the end of the 1990s, this situation had changed drastically. Aside from niche markets, notably including the legal profession, *WordPerfect* had overwhelmingly lost its dominant position. Several factors contribute to the rise of *Microsoft Word* during this period:

- The rise of the *Microsoft Windows* operating system during the 1990s (in relative contrast to its competitors, *Apple Macintosh* and *IBM OS/2*) gave it unprecedented access to burgeoning market of personal computer retailers. This access meant it could conveniently bundle both the operating system and office suite (*Microsoft Office*, of which *Microsoft Word* was and is an integral part) at discount rates to its independent software vendor channel. Neither its operating system nor office suite competitors had such unprecedented global access to their respective markets.

- In turn, its dominance as an operating system vendor gave Microsoft technical advantages in terms of performance and compatibility with its operating system. *WordPerfect*, by contrast, took longer to release versions for both Windows and Macintosh systems. Microsoft first released *Word for Windows* in 1989 (Wikipedia, 2008a); *WordPerfect* appeared in late 1991 (as reported by (Mendelson, 2009)).

- Conversely, the fact that Microsoft continued to sell and support its word-processor on its chief rival operating system, Apple Macintosh, meant that it could boast unrivalled interoperability across platforms. Its competitors were slower to port their software versions to the Apple platform.

- The very issue of interoperability meant that, in the absence of standards, once a market dominant player emerged, the easiest way for users (organisations and individuals alike) to ensure interoperability was to continue to purchase initial and future versions from the same vendor.

This combination of factors, collectively contributing to the "network externalities" effected by market consolidation and the *de facto* standardisation of the Windows platform and Office suite, meant that Microsoft was able to emerge not only as the leading vendor in the office suite market, but in fact to assume a virtually monopolistic position—within the very short space of a decade. This is all the more remarkable given the barriers to entry in this market were to become increasingly low, due to lower costs, improved tools and larger pool of technical labour available for software development. In fact the major competitor to new versions of *Microsoft Office* and *Microsoft Word* were its own predecessors (Hamm, 2006)—the chief marketing hurdle for Microsoft was not how its product differed from competitive offerings, but why its existing customers should bother to upgrade for new features.

Two quotes taken from Microsoft employees in the 1990s give some indication of the extent to which the company prosecuted its now dominant market position. The first is taken from a memo from Bill Gates to several program managers in 1998 (presented as Plaintiff's Exhibit 2991 in Comes versus Microsoft; the anti-trust case launched by the U.S. Government in 1999):

> One thing we have got to change in our strategy—allowing Office documents to be rendered very well by other peoples [sic] browsers is one of the most destructive things we could do to the company.
>
> We have to stop putting any effort into this and make sure that Office documents depends on PROPRIETARY IE capabilities.
>
> Anything else is suicide for our platform. This is a case where Office has to avoid doing something to destory [sic] Windows.
>
> I would be glad to explain at greater length[16].

[16]Comes v. Microsoft (2000a).

The second is an internal marketing manual, this time released by a Microsoft "Technology Evangelist", James Plamondon, suggests that Microsoft make strategic use of "independent" academics, analysts and consultants in promoting its products. The manual is imbued with a suitable mix of religious and military metaphor (one section is titled "Evangelism is War"; another, simply "Jihad"). It states:

> "Independent" analyst's report should be issued, praising your technology and damning the competitors (or ignoring them). "Independent" consultants should write columns and articles, give conference presentations and moderate stacked panels, all on our behalf (and setting them up as experts in the new technology, available for just $200/hour). "Independent" academic sources should be cultivated and quoted (and research money granted). "Independent" courseware providers should start profiting from their early involvement in our technology. Every possible source of leverage should be sought and turned to our advantage[17].

These remarks are indicative of a highly combative company, fiercely protective of its revenues and market share. They also point to the emergence of a more complex game in the software market, involving not merely supplier-customer relations of a *single* product, but an array of intervening, additional and not-always-visible "players"—so-called independent academics, consultants and technical experts, who can be brought into the commercial arena as forms of guerrilla or viral marketing, and, just as vitally, a *platform* comprising a suite of *multiple*, interconnected products. Microsoft was not the only the most company employing such tactics—IBM for example had a long history of leveraging its market dominance into more or less conspicuous forms of economic and political pressure, with its suppliers, customers and competitors alike. In the 1990s Microsoft had, however, in part inherited the mantle of the IT industry "bête noire" from IBM by virtue of its unrivalled predatory excellence. Its relationship to standards and competitors was neatly encapsulated in the phrase "Embrace, Extend, Extinguish", apparently attributed to a Microsoft executive during discussions with Intel in 1995[18]. The phrase referred to a three phased strategy: first, "embrace" a potentially threatening standard (often introduced by Microsoft's competitors); then, "extend" the technology with various enhancements, under the apparent auspices of meeting customer demand; and finally, by virtue of the effect of the enhancements corroding the positive network externalities effected by the standard, "extinguish" its value to customers, and hence its threat to Microsoft's own market share and revenue.

Several indications emerged by the turn of the millennium that this hegemonic position, and the blatantly manipulative practices it entailed, would become unstable. Firstly, and most evidently, the rise of the World Wide Web provided new avenues

[17] Comes v. Microsoft (2000b).
[18] United States v. Microsoft (1998).

for the development and distribution of software, and, just as significantly, a new language for encoding documentation in a plain-text markup that was considerably easier to learn than prior formats. Hypertext Mark-up Language (HTML) put the creation and dissemination of content into a new generation of computer-literate, though not necessarily technically expert, users. HTML, however, was not designed for editable and printable documents, and hence could not yet act as an immediate surrogate to existing office document formats.

Secondly, and alongside the rise of the web, open source software (OSS) became a powerful stimulus for re-considering software licensing models, with the rise of the Linux operating system, the Apache web server software, and a host of other open source projects. Open source software also pointed to a future without restrictive licensing terms, since they were commonly accompanied with "copy-left" licenses such as the GPL license[19]. By the late 1990s, several open source word-processors had become available, though many were arguably limited in features compared with *Microsoft Word*. Ironically, one feature Microsoft's competitors found difficult to emulate was fully-fledged support for *Microsoft Word* documents themselves—the proprietary nature of the document format made choice of software alternatives difficult for organisations with large and growing document corpuses. Nonetheless, there was a clearly evident path towards open source alternatives that were at least feature-rich enough to compete with *Microsoft Office*.

Finally, the monopolistic position of Microsoft itself was motivating governments in both the U.S. and Europe to instigate proceedings designed to protect competition, and limit what were widely deemed to be the anti-competitive practices of the company. The U.S. government filed an antitrust suit against Microsoft in 1998, alleging the company had discriminated against competition in bundling the Internet Explorer web browser with its Windows operating system, using its power as a monopolist in the operating system market to suppress incipient competition in the emerging browser market[20]. The case was severe enough to warrant speculation about potentially splitting the company in two—one to develop the Windows operating system, the other to develop business applications[21]. After considerable legal wrangling over the complex issue of product "tying"[22], the Supreme Court handed down a guilty verdict, but with considerably reduced penalties—principally, that Microsoft not prohibit manufacturers and retailers from including other software on new computers[23]. Nevertheless this, and a subsequent case successfully prosecuted by the European Union, set limits on the extent to which Microsoft could maintain an unrivalled position in the office and word-processing software markets. Coincidentally the EU, along with many national governments, began developing policy frameworks

[19] Free Software Foundation (2007).
[20] Wired News Report (2002).
[21] Hendren (2000).
[22] Chin (2005).
[23] United States District Court (2001).

and commissioning reports on how to bring about greater interoperability through the use of open standards (Ditch, 2007).

8.1.3 The Challenge of the OpenDocument Format

In 1999, Sun Microsystems acquired StarOffice, a German company which had developed a competing office suite of the same name[24]. At the time, Sun supposedly rationalised the acquisition of the company, at a price of $73.5 million USD, as being a cheaper way of providing office software for its own employees than purchasing *Microsoft Office* licenses[25]. Soon after it released the source code as open source under the name of *OpenOffice*. Although it continued to sell *StarOffice*, along with documentation and support, the act of releasing the source code was an important public relations gesture, and the community which developed around the open source version was to become an important activist group. The rise of *OpenOffice*, though still insignificant compared to Microsoft, soon propelled an effort to standardise its XML-based file format. In 2002, the first meeting of the OASIS Open Office Technical Committee (TC) took place[26]. This formalised the standardisation effort under the name of the OpenDocument Format (ODF). In 2005, the ODF format was submitted to the International Standards Organisation (ISO); in 2006, this standard was ratified as ISO 26300[27].

What differentiates the OpenDocument Format from previous document formats? Unlike PDF, PostScript and LaTeX, it is based on XML, which since the turn of the century had become both a *de facto* and *de jure* standard for representing data. ODF is also sufficiently rich in concepts pertinent to generic documents, including spreadsheets, presentations, graphs, equations, diagrams and embedded media—two other document standards, for instance, DocBook and HTML are by comparison considerably simpler, and dedicated to quite specific forms of document representation (book and article semantics, and screen rendering, respectively). Since it is derived from a working office application (originally *StarOffice*, renamed *OpenOffice* shortly after the Sun acquisition), it has been designed to capture faithfully the minutiae of document data—down to international character support and spacing. This is a key requirement for ISO standards in particular[28]. ODF also uses a compressed ZIP format for managing a set of related document assets, which simplifies the transmission, archiving and dissemination of documents. Just as importantly, ODF provides a guarantee of lossless data during the opening and saving of documents.

Yet a document format is unlikely to have been developed were it not for the timely confluence of wide governmental dissatisfaction with the near-monopolistic dominance of a single vendor, the sponsorship of ODF by several powerful rival ven-

[24] Shankland (1999).
[25] Lai (2007).
[26] OASIS ODF Adoption TC (2006).
[27] ISO (2008a).
[28] ISO/IEC (2004).

dors (Sun, and key corporate allies IBM and Novell—and, to a lesser extent, Google, Apple, Oracle and other Silicon Valley stalwarts), and an increasingly active and vocal open source community. Rich document formats are not only the valued intellectual property of their owners; they are extremely intricate and costly to develop. Whereas LaTeX, DocBook and HTML are of a size that they could conceivably be developed, documented and steered by dedicated individuals or small cohorts, the current published version of OpenDocument Format (1.1) is a 700-page specification, covering everything from document metadata to precise typesetting rules, graphs, charts and animations[29]. Sun Microsystem's successful moves to release both the source code to its office applications, and to sponsor (through the contribution of its employees) the development and review of the OpenDocument Format may have had a pragmatic motive of threatening its competition, but doubtless it accelerated the examination of organisational document management policy and licensing the world over. Combined with this, a large and heterogeneous community seized upon these moves as further corroboration of the merits of open source and open standards, both practically and ideologically. Coupled with the technical advantages of ODF over its precursors, this set the scene for the greatest challenge yet to Microsoft's office suite, and indeed, to its entire stable of products built around its Windows and Office platforms.

8.1.4 Microsoft Responds

Not to be outdone, Microsoft quickly responded with its own standardisation effort around its Office format. Despite wide-ranging scepticism over its moves in this direction, it represented a marked change in attitude from its position in the 1980s and 1990s, when the proprietary, closed nature of its formats was a critical aspect of its market strategy. At the time, this not only protected the company from potential competition in the office software market; competition in this market was also potentially corrosive of the company's overall fortunes, since the Windows operating system and a range of subsidiary products belonging to the Windows platform benefited from *Microsoft Office*'s dominant position in the market. As the figures below show, even up until recently Microsoft's fortunes and market position had not been overly effected by these threats.

Microsoft by Numbers

In the recent period of the so-called "format wars", *Microsoft Office* continued to be a highly profitable product of a very profitable company. In its six monthly (July-December) SEC filings for 2007-2008, Microsoft reported overall revenue figures of $30.129 billion, $12.399 billion in operating income and $8.996 billion in net income (all figures in USD)[30]. Its MS Business Division (MBD), of which *Microsoft Office*

[29]Microsoft Corporation (2008b).
[30]Microsoft Corporation (2008b).

Table 8.1: Comparison of IT Company Financials (end of 2007)

	MS	*MBD*	*Google*[a]	*Sun*[b]	*IBM*[c]	*Novell*[d]	*Corel*[e]
Revenue	30,129	8,921	8,297	6,834	27,314	466	125
Operating income	12,399	5,801	2,542	325	6,560	(28)	3
Net income	8,996		2,101	349	4,722	(22)	(14)
Market Capitalisation[f]	263.02		148.18	14.03	160.48	2.38	0.25

[a] Google (2008a).
[b] Sun Microsystems (2008).
[c] IBM Corporation (2007).
[d] Novell (2007).
[e] Corel Corporation (2007).
[f] In billions, USD. Market capitalisation figures taken from Google Finance, on the 28th of February, 2008 (Google, 2008a).

sales "generate over 90% of MBD revenue", reported in the same period $8.9 billion in revenue and $5.8 billion in operating income. The filings include the following note:

> For the remainder of fiscal year 2008, we expect revenue to continue to increase over the prior year due to the strong performance of 2007 Microsoft Office system[31].

Put in context, StarOffice's purchase price ($72 million) represents (notwithstanding the eight year gap) a mere 1.24% of the six monthly operating income of the Microsoft division responsible for *Microsoft Office*. Just as strikingly: within this division (which includes its own manufacturing, packaging, sales, marketing and administrative costs), costs were just 35% of revenue—which compares well even against the company's overall impressive figure of 59%. Table 8.1 shows how Microsoft compares with several other US information technology companies who figure prominently in the controversy. (Note: in some cases most recent figures are quarterly or annual only—these figures have been artificially converted to six-monthly figures for comparison, by doubling quarterly, or halving annual results. All figures are in USD millions unless otherwise indicated).

Not only, then, was Microsoft clearly the dominant force in the IT industry in absolute size, these numbers also show the ongoing high profitability of software licensing as a business model—by comparison, advertising (Google), and hardware and services (Sun, IBM and Novell) are considerably less lucrative. In the context of such enormous fiscal results, even record-setting fines like those imposed by the European Union against Microsoft for breaching anti-competitive practices—page 300 of the ruling stipulated "a fine of EUR 497,196,304"[32]—seem diminutive. Moreover, these

[31] Microsoft Corporation (2008b).
[32] Commission of the European Communities (2004).

figures show a year-on-year increase of 28% (although the release of Office 2007, along with strong PC sales in this period, go some way towards explaining that growth). Needless to say, so far the challenge of the OpenDocument Format had been muted—at least in direct financial terms.

Microsoft "Interoperates"...

Both the memorandum and the manual quoted above were released during the US anti-trust case, which ran from 1998 to 2002. Perhaps as a consequence of this—of both the legal, and potentially far more damaging, the public relations ramifications—the company's tactics in the recent debate have become more subtle, its strategies more implied than stated, at least on public record. Sceptics, including at least one noted commentator, would continue to find the company's practices utilised much the same manipulative methods[33]. Regardless, standardisation and interoperability—"soft", apparently cooperative tactics—now began to play complementary key roles in Microsoft's strategy to retain market share and profitability, particularly in relation to its office suite software.

Microsoft's shift towards increasing standardisation and interoperability can be charted through its office software versions. In 1999, with the release of *Microsoft Office 2000*, documents could be saved in HTML format, and published on the Internet (although these could be viewed only with considerable difficulty and lack of fidelity by non-Microsoft browsers). With the release of *Microsoft Office 2003*, Word, Excel and PowerPoint documents could also be imported and exported in XML format, which permitted the use of a range of XML technologies to query, manipulate and transform the documents. The XML schemas provided by Microsoft were at the time complex and required significant reverse engineering to interpret all but the most trivial documents. However, that documents could be both parsed and generated by third-party software was a major step forward for engineers involved in document workflow and conversion software development (Lenz et al., 2004). These schemas formed the basis for Microsoft's subsequent submission of a rival open document format to Ecma International, a private member-based standards organisation, in December, 2005[34]. This format was named Open Office XML (OOXML); intentionally or otherwise, this set the stage for both comparisons and confusion with OpenDocument Format (ODF—also expressed in XML). A version of OOXML was then included in *Microsoft Office 2007.* Ecma approved the standard in December 2006—however, this approval carried little weight in and of itself, since the two chairs of its supervising technical committee were themselves senior Microsoft executives[35]. (The population of technical committees by employees of the company promoting standards is not unusual—for example, the OASIS technical committee overseeing the development of the OpenDocument

[33] Jones (2008b).
[34] Ecma International (2008c).
[35] Ecma International (2008b).

Format was similarly led by employees of Sun Microsystems and IBM[36]). The main objective was to mirror the ODF progression towards rapid ISO ratification as an alternative open document format—Ecma International played (and continues to play) a similar shepherding role to OASIS in the case of ODF. In 2007, OOXML was submitted to ISO; but failed to get sufficient votes to be ratified. The controversy and publicity surrounded this submission are analysed further on below.

Why then did Microsoft embark upon a program, contrary both to its express attitude and clear financial incentives, to open up its document formats to a standardisation process? One obvious reason is concern over the rise of ODF as a creditable document format. The same SEC filings cited above include a mandatory report on business risks—and high on its list, Microsoft includes the threat of changing business models and competition due to open source software, and concern over "government litigation and regulation activity"[37]. Meanwhile, successful advocacy has seen ODF rise from obscurity to a potential format for both software interoperability and long-term document preservation. This begs the corresponding question of why Microsoft did not then instead support ODF in its office software. At face value the decision to develop OOXML appears part of a hedging strategy, designed both to satisfy customers—particularly governments—of Microsoft's commitment to openness, and simultaneously to preserve control over the technicalities of the format. However, as the analysis below aims to show, this simple explanation is complicated by a number of factors.

8.2 A Tale of Two Formats

8.2.1 Preliminary Remarks

The coverage of the controversy proceeds in two parts. I first conduct a technical analysis of the formats in some detail. This analysis shows how decisions involved in designing the specifications are themselves pivotal "moves" in the overall game of standardisation. As their respective sizes indicate (700 pages for ODF; 6000 pages for OOXML), this is necessarily be a cursory analysis, and aims to capture something of the overall flavour of the two formats. I then pursue a sociological analysis of the standardisation controversy itself. As suggested earlier, the analysis operates in a broadly game-theoretic fashion—although the specifically rationalistic calculations of utility commonly employed by game theory are not pursued here, the metaphor of a game is nevertheless particularly apposite to this study. From the standpoint of someone engaged in interpreting, translating, converting, integrating or choosing between these two formats, the social study should augment the technical one by making explicit what are otherwise implicit perspectival differences on what sorts of things documents are—by highlighting in particular the way those perspectives are

[36] OASIS (2008).
[37] Microsoft Corporation (2008b).

shaped by economic, political, legal and cultural distinctions. The argument advanced throughout this study is that no formal specification alone can bring to light each of the assumptions brought to bear on the domain under consideration. A supplementary sociological analysis is needed to bring into the open the various viewpoints of the designers of these specifications, bearing in mind that such analysis is itself always subject to yet further perspectival presumptions. In this particular case, more than perhaps most—conducted as it is upon a global stage, and being so rich in political intrigue, economic interest and legal complexity—untangling these assumptions is best a partial undertaking. Nevertheless it presents a dynamic, hybridised *socio-technological* model of commensurability of these formats, tailorable to the needs of particular scenarios.

To use a metaphor which features prominently below, what is the proposed pay-off for undertaking this analysis? What is presented here is ideally a model of analysis applicable to any ontology matching or document harmonisation work. It might well be argued that social and political differences are irrelevant to the task of translating apparently mechanical concepts belonging to world of documents. However, such work is itself never conducted in a vacuum. The same organisations undertaking translations, conversions or evaluations of document formats also make weighty policy decisions on document management issues; they consider multi-million dollar software licensing purchases; and they expend significant effort in conducting requirement analysis exercises to determine the scope of work of new projects, including those of data conversion, software migration and document management. Asking the question of commensurability in these cases brings into play non-technical decision-making criteria. Understanding differences along a series of both technical and social dimensions ought ideally, then, to have the practical pay-offs of delivering more accurate project estimates, saving money in IT expenditure, making decisions that align with policy goals and directives, and serving the needs of document users more effectively.

8.2.2 Two Formats Compared—Technical Analysis

Current drafts of both the ODF and OOXML specifications are long: the ODF specification reviewed here (version 1.1) is 738 pages[38], while the OOXML specification reviewed (1.3, draft) is contained in five documents totalling six thousand pages—the main technical reference, *Open Office XML Part 4—Markup Language References*, stands at 5219 pages alone[39]. By way of comparison, current versions of two standards mentioned earlier, HTML and DocBook, have specifications which stand at 389 and 15 pages respectively (Raggett et al., 1999; Walsh, 2009). An exhaustive treatment of each of these formats, perhaps for purpose of developing document conversion tools, would need to analyse each and every concept in both of these formats (conversion tools already exist—see for example the open source project supported by

[38] Durusau et al. (2006).
[39] Ecma International (2008b).

both Novell and Microsoft[40]—however, a comprehensive mapping has not yet been undertaken). The following analysis does not aim for such exhaustiveness, but rather to capture the salient differences between the two formats. It is enough therefore to show here that the formats have markedly alternate *conceptualisations* of documents, which issue from different circumstances, goals, beliefs and motivations of the participating actors. The subsequent section examines how these factors—both those explicit in the peripheral literature on the formats, and those implicit in the format specifications themselves—can be tied back to the broadly social characteristics of the game of standardisation, of which the formats themselves comprise key strategic moves.

The technical analysis then examines four areas of comparison: the *schemas* and *namespaces* in which the concepts of the formats are defined and organised; the organisation of documents into *packages*; the handling of document *metadata*; and the basic *textual elements* of a very simple document. Several salient technical differences considered in other studies are also discussed here.

Schemas and Namespaces

Both ODF and OOXML formats are designed to capture the terms required for office documents, and both declare a number of *schemas* and *namespaces* for describing different kinds of related document concepts. *Namespaces* are modules of *elements* and *attributes* which are in some way related (Bradley, 2003). Elements and attributes are syntactic elements of XML, which are frequently used to model semantic concepts and relations—one approach to modelling OWL classes and properties, for instance, would be to treat them syntactically as elements and attributes. Elements can *contain* both attributes and other elements, though such containment is also a purely syntactic feature. In the case of a highly simplified document format represented in XML, elements could conceivably include concepts like *document*, *paragraph* and *comment*; attributes might include *document title*, *paragraph width* and *comment author*.

The specification of elements and attributes is usually performed in XML via a *schema*, using a standardised XML definition language like Document Type Definition (DTD), XML Schema or RelaxNG. While Document Type Definitions are a foundational part of the older SGML standard[41], XML Schema and RelaxNG are newer definition languages which provide greater expressivity for the constraints in which elements and attributes are arranged. XML Schema is authored by the World Wide Web Consortium[42]; RelaxNG has been developed by the OASIS standards group (the same body responsible for the development of the ODF)[43]. Though the subject of its own (though less public and acrimonious) format debate, the differences are minimal between XML Schema and RelaxNG, largely a matter of style for most ap-

[40] ODF Converter Team (2009).
[41] Maler and El Andaloussi (1999).
[42] Walmsley and Fallside (2004).
[43] Clark and Makoto (2001).

plications (van der Vlist, 2002). Any XML document which is purely syntactically correct is said to be *well-formed*; a document is also *valid* if it conforms to some schema, i.e. does not violate the constraints set out by that schema. A schema must have a *namespace*, which must be unique within the scope of the system processing schema-conforming documents. For schemas intended for public adoption, namespaces are typically *unique resource identifiers* (URI's), which are guaranteed to be unique across the world wide web. Metadata standards—such as the DublinCore, a set of elements for describing document metadata[44]—are typically expressed in schemas with a unique URI namespace. A schema may be specified in one or more physical files; additionally, a single file can define multiple schemas. The use of public namespaces is an important mechanism for linking schemas without a common author; it permits any public schema definitions to be *imported* into another schema.

ODF and OOXML are both specified in a number of schemas, each with an associated namespace. ODF 1.1 is defined in a single file, comprises 22 namespaces, and utilises RelaxNG for defining elements and attributes. OOXML is defined in a total of 90 files, comprising a total of 27 namespaces, and utilises XML Schema. Seven of the 22 ODF schemas in fact reference other standardised schemas, including ones defined for typesetting, metadata, graphics and mathematical notation. All of the OOXML namespaces reference other schemas defined within OOXML itself, with the exception of the DublinCore schema. Table 8.2 summarises these differences.

Table 8.2: Overall Schema Comparison

	ODF 1.1	**OOXML 1.3 draft**
# of files	1	90
# of declared namespaces	22	27
# of imported namespaces	7	1
# of declared elements[1]	536	3427
# of declared attributes[1]	1608	3374
XML formalism	RelaxNG	XML Schema

The schemas themselves describe various features of documents. Each format covers three types of document content: textual content (produced by word-processing software); tabular content (produced by spreadsheet software); and presentational content (produced by presentation software). Absent are definitions of data commonly produced by other office software: databases, email, notes, project management charts, and so on. An important design consideration motivating the division of schemas is the separation of content from other aspects of the document, such as styles, metadata, application settings and package information. The structural separation permits other systems to interrogate the document for just the information they require: a search engine may only be interested in the content parts of the doc-

[44]DCMI (2008).

ument, a cataloguing system in the metadata, and so on. The distinction between document aspects is also evident in the discussion of package structures below.

Despite differences, the formats share many features at an abstract level. Both ODF and OOXML have three central schemas for describing each of the document types (documents, spreadsheets and presentations). For convenience these are classified here as "core" schemas. The document types also have numerous shared characteristics, which are described by the remaining schemas. These include document packaging, container and metadata information (termed here "meta-level" schemas); and constructs for drawing, graphing and charting, mathematical notation, bibliographic data, forms, and custom or user-defined schemas (termed "detail" schemas). These schemas intersect with the specific document type schemas in a lattice-type structure: package, container and metadata schemas embed the core, content-specific schemas; these in turn embed the detail schemas.

Figure 8.1 depicts these abstract schematic relations. This depiction is a loose approximation, and indicates only the general arrangement and dependencies between schemas (which flow from meta to core to detail schemas). Table 8.3 is a more detailed mapping of the schemas to each other—while a general indication of purpose of the schemas is provided here, they are naturally documented at greater length in the respective specifications themselves[45].

[45] Durusau et al. (2006); Ecma International (2008b).

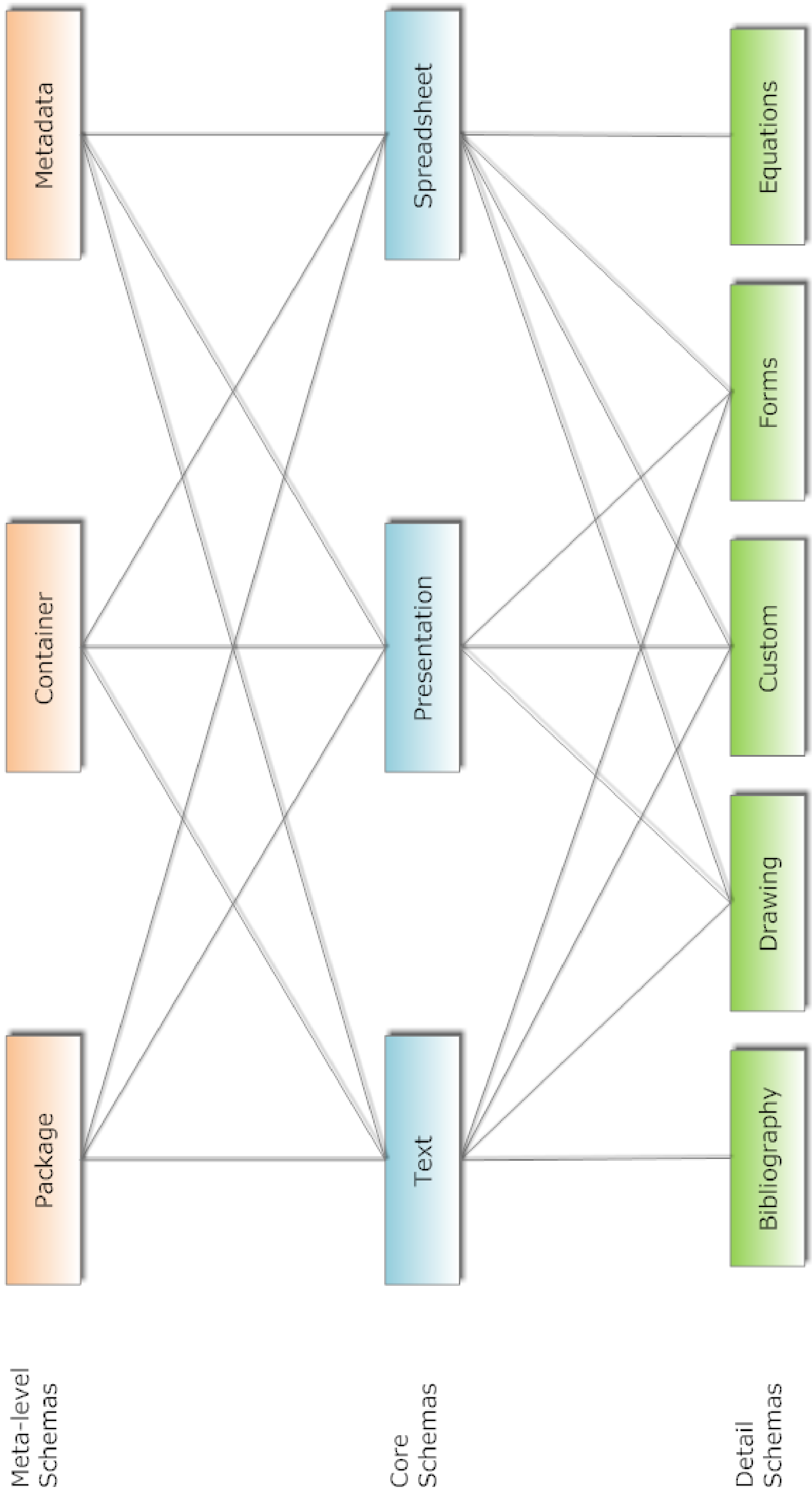

Figure 8.1: Overview of Schema Composition

Table 8.3: Comparison of Namespaces

Area	*Functional area*	*OpenDocument Format (ODF)*	*Open Office XML (OOXML)*
Meta	Container for document parts	office	OfficeDocument
Meta	Document configuration	config, manifest	Characteristics
Meta	Document relationships	**xlink**	Relationships
Meta	Document Metadata concepts	meta; **dc [DublinCore]**	Metadata {*CustomProperties, ExtendedProperties, VariantTypes*}[a]; **dc [DublinCore]**
Core	Textual document concepts	text	WordprocessingML {*Main*}
Core	Tabular-styled document concepts	table	SpreadsheetML {*Main*}
Core	Presentation document concepts	presentation	PresentationML {*Main*}
Detail	Embedded drawing objects in document	drawing; dr3d; anim; chart; **svg**; **smil**	DrawingML {*Main, Compatibility, Diagram, LockedCanvas, Picture, SpreadsheetDrawing, WordprocessingDrawing*}; VML {*Main, OfficeDrawing, PresentationDrawing, SpreadsheetDrawing, WordprocessingDrawing*}[b]
Detail	Charts	chart	Chart; ChartDrawing
Detail	Embedded forms in documents	form; **xforms**	—[c]

Table 8.3: Comparison of Namespaces

Area	*Functional area*	*OpenDocument Format (ODF)*	*Open Office XML (OOXML)*
Detail	Embedded script fragments in documents (such as macros)	script	activex
Detail	Document styling	style	—[c]
Detail	Number concepts	number	—[c]
Detail	Print formatting	**fo**	—[c]
Detail	Mathematical notation	**math**[d]	Math
Detail	Supports embedding user-defined schemas	—[d]	CustomXML
Detail	Embedded citations	—[d]	Bibliography

Schema names in bold have been imported from other standards. The prevalence of imported schemas in ODF is indicative of a stated objective to "'borrow' from similar, existing standards wherever possible and permitted" (Valoris, 2003). Conversely, the choice to define schemas in areas such as mathematical notation, graphics and forms suggest that OOXML has placed significantly greater emphasis on compatibility with the overwhelming preponderance of existing *Microsoft Office* documents. Rather than follow newer standards like MathML, SVG and XForms in these respective areas, OOXML is modelled on how previous *Microsoft Office* binary formats have treated such objects. A thorough review of compatibility would need to examine just how these respective "detail" schemas for mathematical notation, graphics and forms also align. One advantage of ODF approach in this regard is the ease with which other software developed around these standards can extract and manipulate data conforming to these standards, while being agnostic of the OpenDocument Format itself. The question of backward compatibility is a concern for both formats; assum-

[a] Braces are used here to indicate namespaces (e.g. *Diagram)* within a broader functional grouping area of OOXML (e.g. DrawingML).

[b] See discussion below for distinction between DrawingML and VML in OOXML.

[c] Form, styles, numbers and print concepts are defined within the core schemas in OOXML. For example, WordprocessingML defines styles and form information for textual documents; SpreadsheetML defines styles in tabular documents, and so on.

[d] At this stage, ODF does not define concepts for handling formulae or custom XML schemas. Support for formulae and extensible schemas are planned for version 1.2 (Durusau and Brauer, 2007). Bibliographic entries are supported within the *text* schema.

ing a sufficient body of documents in ODF 1.1 format, future iterations of the format will need to consider the need to support this version itself, as well as versions of its externally referenced schemas like MathML.

The difficulty of handling legacy documents while supporting improved data models is evident with the introduction of two separate schema collections in OOXML for handling graphical data. In the OOXML Primer document, DrawingML is considered the canonical method for describing embedded shapes, colours, styles and effects[46]. VML (Vector Markup Language) is a XML format for graphics introduced by Microsoft in 1998[47], and at that time failed to be accepted as a standard. Nevertheless, it was adopted in MS Office 2000, and consequently requires inclusion in OOXML in order to support documents created in this and subsequent versions up until MS Office 2003. On this subject, the OOXML Primer states:

> The VML format is a legacy format originally introduced with Office 2000 and is included and fully defined in this specification for backwards compatibility reasons. The DrawingML format is a newer and richer format created with the goal of eventually replacing any uses of VML in the Office Open XML formats. VML should be considered a deprecated format included in Office Open XML for legacy reasons only and new applications that need a file format for drawings are strongly encouraged to use DrawingML in preference[48].

The redundancy of including two graphical formats, one of which is clearly deprecated, in a first version of a specification caused various national bodies commenting upon the ISO submission of OOXML to request its removal or annexation to the main specification[49]. Based on the comment from the ECMA Technical Committee in January, 2008, this recommendation has since been approved: "As suggested by many National Bodies, we will also make the necessary changes to enable the usage of DrawingML everywhere VML was previously used"[50].

The differences at a schema level between the formats can be summarised along the following lines:

1. *Semantic specificity*: the number of physical files, schemas, and declared elements and attributes in OOXML significantly outweighs the equivalent number in ODF, reflecting the general difference in size between the documentation of the two specifications. This is only partially explained in the use by ODF of external schemas—it in part reflects an aim of ODF towards semantic *minimalism* (using a minimal set of concepts, differentiated where necessary with the use of

[46]Ecma International (2008b).
[47]Mathews et al..
[48]Ecma International (2007b). Although, as the discussion of individual documents below indicates, *Microsoft Office* itself does not yet take this advice
[49]Ecma International (2007a).
[50]Ecma International (2008a).

attributes, in other words, *parametrically*), and a converse tendency of OOXML towards semantic *maximalism* (using a maximal set of concepts, differentiating on the basis of classificatory elements). This latter point is expanded in the section below, *A Sample Document in ODF and OOXML*.

2. *External schema re-use*: as explicitly reflected in the statements of both OASIS and ECMA technical committees, ODF is directed towards schema re-use where possible. In contrast OOXML uses concepts almost exclusively defined in internal schemas, in part to support backwards compatibility with earlier XML and binary formats authored by its principal sponsor, Microsoft.

3. *Internal schema re-use*: the differences are less marked here. OOXML redefines particular structures such as tables within each of the core schemas, WordprocessingML, SpreadsheetML and PresentationML. In contrast, ODF uses the same *table* schema in all of its document types. This simplification comes at the cost of specificity—spreadsheets typically include a larger number of rows and columns than word-processing and presentational tables, yet the use of the same model means word-processing and presentation applications need to consider the possibility of large tables being included.

4. *Multiple methods*: OOXML is designed to support existing document created in earlier versions of *Microsoft Office*. In the case of graphical objects, this has led to the inclusion of two overlapping schemas: the VML schema for older documents, and the DrawingML schema, for documents created by *Microsoft Office 2007*. ODF has a single schema set for handling graphical objects.

5. *Formal validation*: ODF uses RelaxNG, while OOXML uses XML Schema. Although the differences are slight, RelaxNG provides a more flexible and humanly-readable model (Clark, 2002), arguably more suited to the loose-fitting nature of document rather than transactional data. It suggests ODF uses a more flexible, descriptive model, while OOXML is comparatively prescriptive, and provides more strict data validation as a result. This reinforces the first point above, that OOXML focuses on greater semantic specificity.

These differences are summarised in the conclusion to the technical analysis.

Packages

Both ODF and OOXML use the ZIP file format as package containers for documents. One implication is that any ODF or OOXML can be opened by conventional decompression software. This was the not the case with previous binary formats. In both cases, the packages contain a number of XML files conforming to the respective format schemas, along with various media assets required by the document, such as images, audio and video. Both formats also permit the inclusion of non-standard, application-specific data, so long as this does not break conformance with the schemas. This is useful for storing particular application or document configuration settings, for example.

The ODF package specification is a brief nine pages[51]; the OOXML package specification has its own document, "Open Office XML Part 2—Open Packaging Conventions", and consumes 131 pages[52]. Again, only the key differences are highlighted here. Whereas the ODF package specification details only the key elements likely to appear in a package (it is therefore both *concrete* and *non-normative*), OOXML outlines both a generic model and specific implementation details for a package, collectively entitled "Open Package Conventions" (OPC)—it is *abstract* and highly *normative* in contrast.

The OPC is designed as generic container for XML files and associated resources—not simply OOXML documents. According to the specification, "It is intended to support the content types and organization for various applications and is written for developers who are building systems that process package content"[53]. The OPC model has three key concepts: *Parts*, *Part Addressing* and *Relationships*. *Parts* are specific "streams of bytes"[54], that is, specific content within the package. *Parts* have names, content types, and "growth hints", which indicate the number of bytes to reserve in the package. There are specific rules in the specification for handling parts with XML content. *Part Addressing* covers how parts are referred to within the package. *Relationships* describe relations between parts and other resources—either within or outside of the package—in a generic way, in order to avoid the problem of "arbitrary markup or an application-specific encoding"[55]. For example, a system with no special knowledge of document formats or other parts of OOXML could conceivably navigate the relationships to determine the resources used by the package—ODF has no such generic facility. Specification of relationships also permits reference to digital certificates, and provides a means for handling version and extensibility issues within the package. Together these concepts provide an abstract model for applications to package and extract data. The package schemas introduced above specify how the relationships, part content types and core properties are stipulated within the package format.

The ODF package format follows a more conventional pattern for embedding package information (see for example the Java Archive Format[56]). The package contents are outlined in a manifest file, which lists the package files names, paths (equivalent to the OPC *Reference* concept), size, media or content type, as well as digital signatures[57]. Unlike the OPC, there is no use of metadata properties within the

[51] OASIS (2008).
[52] Ecma International (2008b).
[53] Ecma International (2008b).
[54] Ecma International (2008b).
[55] Ecma International (2008b).
[56] Sun Microsystems (1999).
[57] OASIS (2008).

manifest description of the package contents—these are only referenced within the document itself. There is also no equivalent abstraction of relationships between files. Instead relationships are inferred by naming conventions spelled out elsewhere in the specification (section 2.1)—in the case of media assets stored in the package, these referred to explicitly within the contents of the document. Using descriptions taken from the specification, the file names and their associated function, quoted from the specification, are as follows:

- *content.xml*—"Document content and automatic styles used in the content"[58].
- *styles.xml*—"Styles used in the document content and automatic styles used in the styles themselves"[59].
- *meta.xml*—"Document meta information, such as the author or the time of the last save action. Application-specific settings, such as the window size or printer information"[60].
- *settings.xml*—"Application-specific settings, such as the window size or printer information"[61].

Alternatively the entire document contents can be stored in a single XML file, of any name.

The abstract model introduced by the OPC makes for a far less intuitive format, as can be seen by the comparison between two basic ODF and OOXML documents below. No effort is made by the ODF package conventions to provide a generic specification for packaged data generally, and this means the files contained with package have simple, self-explanatory names. Conversion between formats would generally need to interpret the abstract OPC relationships, and downgrade these to the concrete form required by ODF; conversely, the ODF files would need to be converted back to an abstract set of relationships when converting in the other direction. Since the package formats are comparatively a small and trivial part of an overall document conversion process, this introduces an unnecessary burden for those undertaking the conversion.

Metadata

Both specifications outline metadata properties, and both allow for further properties to be added by users to a document. Both reference the DublinCore property set, although at time of writing neither major implementation of the formats (*OpenOffice* and *Microsoft Office*, respectively) support these properties directly within their user interface. The ODF does, however, explicitly reference the DublinCore for metadata purposes, while OOXML uses DublinCore for adding metadata properties to the

[58]OASIS (2008).
[59]OASIS (2008).
[60]OASIS (2008).
[61]OASIS (2008).

package format, within the OPC described above. It is the area of metadata that document formats most closely resemble the highly structured formalism of Semantic Web ontologies—indeed DublinCore has been expressed as an OWL ontology[62]. Consistent use of DublinCore is of considerable benefit to content management and workflow systems, citation indexes, and information retrieval software like search engines, providing unambiguous identification and retrieval of documents by author, title, publisher and other metadata fields. That both formats utilise the DublinCore is of considerable potential benefit for these reasons; a content management system could provide a single search interface to users for finding document authored in either ODF or OOXML formats.

This promise is compromised by differences in how metadata is arranged within the two formats. Both separate metadata into three categories, but these are not consonant. ODF stipulates the following categories:

1. *Pre-defined Metadata.* These include the DublinCore metadata set (which include creator, subject, title and other common metadata fields), as well as additional document-specific elements declared within the *office:meta* schema (such as who last printed the document, what template the document uses, and what general statistics have been recorded about the document).

2. *User-defined Metadata.* An arbitrary number of pairs of metadata elements can be added to a document by users. A user-defined metadata element has a *name*, a *value*, and optionally a *value type* (such as whether the value is a string of characters or a number).

3. *Custom Metadata.* An application can add any further arbitrary well-formed XML metadata elements. Such content must be preserved by any system reading and writing ODF documents. This permits application-specific extensibility (for example, a content management system could add properties specifying user roles and rights to the document).

Meanwhile, OOXML defines the following metadata categories:

1. *Core properties.* Core properties include those defined within the OPC (Section 10), namely the DublinCore property set, as well as a separate series of fields roughly equivalent to a subset of the document-specific elements described under ODF's *Pre-defined Metadata* above.

2. *Extended properties.* Extended properties are broadly equivalent to a subset of ODF *Pre-defined Metadata* fields.

3. *Custom properties.* These are equivalent to the *User-Defined Metadata* elements described above.

Table 8.4: Comparison of metadata categories

ODF	**OOXML**	**Defined by**
Pre-defined Metadata	Core Properties	DublinCore
Pre-defined Metadata	Core Properties	Document Format (ODF / OOXML)
Pre-defined Metadata	Extended Properties	Document Format (ODF / OOXML)
User-defined Metadata	Custom Properties	User
Custom Metadata	None / Custom properties?	Application or External System

Table 8.4 contrasts the two sets of metadata categories.

The lack of equivalent for ODF's *Custom Metadata* in OOXML is another sign of the restrictive, normative character of OOXML compared with the ODF. Theoretically, application-specific properties could be added as custom properties; although this does permit user access to these properties, not always a desirable outcome.

On the other hand, OOXML permits both simple and complex properties. Simple properties are equivalent to all ODF properties; they have a name, a value, and a value type. Complex properties permit XML fragments (elements and attributes) of arbitrary complexity. Such properties could be multi-part types, like an event (with a start and end date), some media resource (like pictures or video), or the results of a form. Four of the defined *extended properties* are complex properties—*Digital Signature*, *Heading Pairs*, *Application Specific File Properties*, and *Part Title*. All *custom properties* are treated as complex properties. Complex properties cannot be treated as *User-defined Metadata* in ODF, since it has no support for more than simple name-value properties. Data captured as complex properties in OOXML could be stored as *Custom Metadata* in ODF; however, these would necessarily be invisible to users—the opposite problem to that caused by the absence of a *Custom Metadata* equivalent in OOXML.

Table 8.5 lists the DublinCore elements, their definition as per the DublinCore Metadata Element Set (1.1) and Terms[63], and whether they are used by the ODF, OOXML or both. The definitions are taken directly from the DublinCore documentation[64]. The Element Set itself also contains several useful clarifying comments—for reasons of space these have been omitted.

There are several points worth noting about the use of DublinCore:

[62]DCMI (2008).
[63]DCMI (2008).
[64]DCMI (2008).
[a]Defined in the DublinCore Terms (an extension of the DublinCore Metadata Element Set), which are specialisations of the *Date* element (DCMI, 2008).

Table 8.5: Use of DublinCore properties

Element	**Definition**	**Used by**
Contributor	An entity responsible for making contributions to the resource.	Neither
Coverage	The spatial or temporal topic of the resource, the spatial applicability of the resource, or the jurisdiction under which the resource is relevant.	Neither
Created[a]		OOXML
Creator	An entity primarily responsible for making the resource.	Both
Date[a]	A point or period of time associated with an event in the lifecycle of the resource.	Both
Description	An account of the resource.	Both
Format	The file format, physical medium, or dimensions of the resource.	Neither
Identifier	An unambiguous reference to the resource within a given context.	OOXML
Language	A language of the resource.	Both
Modified[a]		OOXML
Publisher	An entity responsible for making the resource available.	Neither
Relation	A related resource.	Neither
Rights	Information about rights held in and over the resource.	Neither
Source	A related resource from which the described resource is derived.	Neither
Subject	The topic of the resource.	Both
Title	A name given to the resource.	Both
Type	The nature or genre of the resource.	Neither

1. In relation to the *Creator* element, the OpenDocument Format (3.1.7) specifies: "The <dc:creator> element specifies the name of the person who last modified the document. The name of this element was chosen for compatibility with the DublinCore, but this definition of 'creator' used here differs from DublinCore, which defines creator as 'An entity primarily responsible for making the content of the resource.' In Open Document terminology, the last person to modify the document is primarily responsible for making the content of the document" (OASIS, 2008). This differs from OOXML, which simply assumes the *Creator* element to be document's author.

2. The ODF fields *Creation Date and Time* and *Modification Date and Time* fields listed below in fact use the DublinCore *Date* element, just as the Created and Modified DC terms do—so these fields can be assumed to be equivalent.

The majority of the properties are defined by the document formats themselves (either as ODF *Pre-defined Metadata* or OOXML *Core* and *Extended Properties*). These are listed in Table 8.6.

Table 8.6: Comparison of Metadata Properties

ODF	**OOXML**	**Type**
Generator	Application name	Simple
Keywords	keywords *[Core]*	Simple
Initial Creator		Simple
Printed By		Simple
Creation Date and Time	created *[Core—DC]*	Simple
Modification Date and Time	modified *[Core—DC]*	Simple
Print Date and Time		Simple
Document Template	Name of Document Template *[Extended]*	Simple
Automatic Reload		Simple
Hyperlink Behaviour		Simple
Editing Cycles		Simple
Editing Duration		Simple
Document Statistics[a]		
	category *[Core]*	Simple
	contentStatus *[Core]*	Simple
	contentType *[Core]*	Simple
Creator[b]		
	lastModifiedBy *[Core]*	Simple

Table 8.6: Comparison of Metadata Properties

ODF	OOXML	Type
	revision *[Core]*	Simple
	version *[Core]*	Simple
	Application version *[Extended]*	Simple
Document Statistics[a]	Total Number of Characters *[Extended]*[a]	Simple
Document Statistics[a]	Number of Characters (With Spaces) *[Extended]*	Simple
Document Statistics[a]	Name of Company *[Extended]* Digital Signature *[Extended]*[c] Document Security *[Extended]* Heading Pairs *[Extended]*	Simple Simple Simple Complex
Document Statistics[a]	Number of Hidden Slides *[Extended]*	Simple
	Hyperlink List *[Extended]*	Complex
	Relative Hyperlink Base *[Extended]*	Simple
	Hyperlinks Changed *[Extended]*	Simple
Document Statistics[a]	Number of Lines *[Extended]*	Simple
	Links Up-to-Date *[Extended]*	Simple
	Name of Manager *[Extended]*	Simple
	Total Number of Multimedia Clips *[Extended]*	Simple
	Number of Slides Containing Notes *[Extended]*	Simple
Document Statistics[a]	Total Number of Pages *[Extended]*	Simple
Document Statistics[a]	Total Number of Paragraphs *[Extended]*	Simple

Table 8.6: Comparison of Metadata Properties

ODF	OOXML	Type
	Intended Format of Presentation *[Extended]*	Simple
	Application Specific File Properties *[Extended]*[d]	Complex
	Thumbnail Display Mode *[Extended]*	Simple
	Shared Document *[Extended]*	Simple
	Slides Metadata Element *[Extended]*	Simple
	Part Titles *[Extended]*	Complex
	Total Edit Time Metadata Element *[Extended]*	Simple
Document Statistics [a]	Word Count *[Extended]*	Simple

Of a total of forty-four properties, seven of ODF properties have no equivalent OOXML value (nor, due to the lack of extensibility, any way of adding these other than as Custom (user-defined) Properties); 23 of the Core and Extended OOXML properties have no ODF equivalents (although—except in the case of the complex properties, *Heading Pairs*, *Hyperlink List*, *Application Specific File Properties* and *Part Titles*—these could be added as ODF *Custom Metadata*). The remaining 31% of properties are common to both formats.

In the case of document statistics, there is again rough but incomplete overlap. As table 8.7 below shows, six of the statistics are common to both formats; ODF contains eight not reproduced in OOXML, and OOXML contains three not reproduced in ODF. Around 35% of statistics produced in one format could therefore be meaningfully translated into the other.

This analysis of metadata shows that even in the use of the same metadata standard (DublinCore), there is not perfect commensurability. In the use of format-specific

[a] This field contains the individual document statistics, many of which map to OOXML equivalents. See discussion below for further details.

[b] See 8.5, Note 2 above.

[c] Embedding a digital signature in a document's property has been deprecated in favour of the method described in the Open Package Conventions (OPC). The *Digital Signature* field appears to have been retained for backward compatibility reasons only .

[d] The *Application Specific File Properties* field lists all of the extended properties supported by the OOXML application itself. It appears this field cannot be extended by further arbitrary properties by an given OOXML application.

Table 8.7: Comparison of Statistical Properties

ODF	**OOXML**
Page Count	Total Number of Pages
Table Count	
Draw Count	
Image Count	
Object Count	Total Number of Multimedia Clips
OLE Object Count	
Paragraph Count	Total Number of Paragraphs
Word Count	Word Count
Character Count	Number of Characters (With Spaces)
Row Count	
Frame Count	
Sentence Count	
Syllable Count	
Non Whitespace Character Count	Total Number of Characters
	Number of Hidden Slides
	Number of Lines
	Number of Slides Containing Notes

document information and statistical metadata, roughly one third of properties are common. While there are ways of capturing exclusively OOXML metadata in ODF, this would have no semantic significance for applications producing and consuming ODF documents—they would need to honour the syntactic containers of the metadata, but would not be able to update or render this information meaningfully. In the case of the four complex properties, this information can at best be captured as an undifferentiated stream of XML characters. Going the other way, the situation is much the same—possibly ODF-only properties can be rendered as OOXML *Custom Properties*, although in the case of automatically generated fields (such as *Print Date* and *Time* and exclusive statistical figures), this information could quickly become out-of-date and erroneous. In such cases it would preferable not to include such metadata at all. Data staleness is a potential problem in both conversion cases, especially for properties which are updated automatically by the application, rather than the end user.

There do not appear to be major significant design differences in how metadata is conceived. Several OOXML metadata properties appear obscure and complex, and related to application behaviour than document description. This may be for the purpose of preserving backward compatibility with legacy *Microsoft Office* formats. ODF also appeared to be more flexible and extensible.

A Sample Document in ODF and OOXML

By far the bulk of both ODF and OOXML specifications is naturally dedicated to the actual contents of textual, tabular and presentational documents. An exhaustive treatment of these elements is beyond the scope of this study, but it is useful to compare some of the central elements used in word-processing documents to capture the flavour of how each format structures document content. For this purpose the word-processing software packages of *OpenOffice 2.3* and *Microsoft Office 2003* equipped with the *Microsoft Office Compatibility Pack* has been used to generate, respectively, an ODF document and an OOXML document. The contents of the document utilise several basic word-processing features—formatting, embedded links and images—as follows:

> **Sample Document**
> This has some **bold formatting**, also some *with italics*, a web link and a picture. . . [followed by the picture itself]

The content is the same as that used in a recent technical report, "Technical Distinctions of ODF XML and OOXML" (Macnaghten, 2007)—although the purpose of that paper is somewhat distinct from those of this study, the use of the same minimal text and formatting allows for comparison with its results. The original image has replaced with one of my own. Appendix B.1 demonstrates how this content appears in each of the software programs.

After saving the documents as, respectively, *SampleDocument.odt* for ODF and *SampleDocument.docx* for OOXML, their contents were extracted using a common ZIP format decompression utility. Conventional file and text editing software were then used to view the resulting directory structure and text contents[65].

Once extracted, the ODF document, *SampleDocument.odt*, expanded into the following directory structure:

```
Configurations2/
Configurations2/accelerator/
Configurations2/accelerator/current.xml
Configurations2/floater/
Configurations2/images/
Configurations2/images/Bitmaps/
Configurations2/menubar/
Configurations2/popupmenu/
Configurations2/progressbar/
Configurations2/statusbar/
Configurations2/toolbar/
```

[65] As a side note: prior to the introduction of these non-binary formats, it would not have been possible even to inspect the contents of *OpenOffice* or *Microsoft Office* documents using generic utilities in this way.

```
META-INF/
META-INF/manifest.xml
Pictures/10000000000001C000000150C4FD0C84.jpg
Thumbnails/
Thumbnails/thumbnail.png
content.xml
meta.xml
mimetype
settings.xml
styles.xml
```

The *Configurations2* directory contains a range of settings, and the *Thumbnails* directory contains a small image showing the first page of the document—these are application-specific, and not part of the ODF standard. The *manifest.xml* file contains the package information, while the *content.xml*, *meta.xml*, *settings.xml* and *styles.xml* fields are briefly described in the *Package* section above.

The OOXML document, *SampleDocument.docx*, expanded into the following directory structure:

```
docProps/
docProps/app.xml
docProps/core.xml
\_rels/
\_rels/.rels
word/
word/\_rels/
word/\_rels/document.xml.rels
word/media/image1.jpeg
word/theme/
word/theme/theme1.xml
word/document.xml
word/fontTable.xml
word/setting.xml
word/style.xml
word/webSettings.xml
[Content\_Types].xml
```

While the file names are similar, unlike the ODF they are essentially arbitrary, and are identified functionally according to the Open Package Conventions described above in the *document.xml.rels* file.

Both formats rely heavily upon a "separation of concerns"—different files contain data conforming to different schemas, which in turn reflect different conceptual aspects of the document. Consequently, package, metadata, setting and style information is separate to the content. The *content.xml* file in the ODF structure and the *document.xml* file in the OOXML structure contain the content proper of the document; the respective contents of these files are listed below.

Structurally, the relevant parts of each document content can be presented in the following hierarchical form:

ODF

```
- office:document-content
   - office:body
      - office:text
         - text:h
            - "Sample Document"
         - text:p
            - "This has some"
            - text:span [@text:style-name = "T1"]
               - "bold formatting"
            - ", also some "
            - text:span [@text:style-name = "T2"]
               - "with italics"
            - ", a "
            - text:a [@xlink:href = "http://www.w3.org/"]
               - "web link"
            - " and a picture..."
         - text:p
            - draw:frame
               - draw:image [@xlink:href =
                   "Pictures/10000000000001C000000150C4FD0C84.jpg"]
```

OOXML

```
- w:document
   - w:body
      - w:p
         - w:pPr
            - w:pStyle [@w:val = "Heading1"]
         - w:r
            - w:t
               - "Sample Document"
      - w:p
         - w:r
            - w:t
```

```
            - "This has some "
      - w:r
         - w:rPr
            - w:b
            - w:bCs
         - w:t
            - "bold formatting"
      - w:r
         - w:t
            - ", also some "
      - w:r
         - w:rPr
            - w:i
            - w:iCs
         - w:t
            - " with italics"
      - w:r
         - w:t
            - ", a"
      - w:hyperlink [@r:id = "rId4"]
         - w:r
            - w:rPr
               - w:rStyle
            - w:t
               - "web link"
      - w:r
         - w:t
            - " and a picture..."
   - w:p
      - w:pPr
      - w:r
         - w:pict
            - v:stroke
            - v:formulas
            - v:path
            - o:lock
         - v:shape
            - v:imagedata [@r:id = "rId5"]
   - w:sectPr
```

Both formats wrap the contents in a document and body element; thereafter, they diverge in how they handle actual textual data. Table 8.8 depict the ODF and

OOXML elements and attributes (prefixed with "@") used in these documents, with a brief explanation. Elements are juxtaposed if their function is sufficiently similar, but this ought not imply precise semantic equivalence.

Table 8.8: Textual Elements and Attributes

ODF Elements and Attributes	*OOXML Elements and Attributes*	*Description*
`document-content`	`document`	Root element, contains all of the document contents.
`body`	`body`	Contains the content body.
text		Indicates textual (as opposed to tabular or other kind of) content
`h`		Indicates a heading (OOXML equivalent must be defined in the referenced style—see note below)
`p`	`p`	Indicates a textual paragraph
	`pPr`	Contains paragraph properties—generally a *pStyle* element with a *val* attribute which references the paragraph's style
`@style-name`	`pStyle[@val]`, `rStyle[@val]`	References a style for the containing paragraph or run
`span`	`r`	Indicates a span or run of text
	`rPr`	Contains the run's properties (if these differ from the containing paragraph)—generally a *rStyle* element with a *val* attribute which references the run's style
	`t`	Contains actual text of the run
	`i`	Indicates the text must rendered italicised (ODF equivalent must be defined in the referenced style—see note below)

	`b`	Indicates the text must rendered bold (ODF equivalent must be defined in the referenced style—see note below)
`a`	hyperlink	Indicated the enclosed text is a hyperlink (*a* stands for the "anchor" of a hyperlink)
`@href`	`@id`	Contains the reference (ODF) or relationship ID (OOXML) for a resource, such as a web link or image
`frame`	`pict`	Indicates some embedded object (in the OOXML case, the object must be a picture)
	`shapetype`	Specifies key properties of a shape, including the stroke, formulas and path of the shape
	`shape`	Indicates a shape, which may be an image or some other graphical object
`image`	`imagedata`	Indicates an image (the image itself is referenced by the href or id attribute on this element)
	`sectPr`	Contains the section's properties. Even if no sections are included explicitly, the document has a default section, which specifies page size, layout, columns and grid dimensions.

Table 8.8 indicates what might be described as the best fit between the key elements in the two documents. However, six ways in which the two formats differ have been identified in this review of document structure:

1. **Verbosity**. Structurally the ODF document is considerably more terse—this is due to its use of *mixed content*, where XML elements can be interweaved with

standard text. ODF shares this feature with HTML, and it makes for code which is considerably easier to read and write (Carrera et al., 2005). The OOXML model does not permit mixed content, and so suffers from an extrapolated structure. From a machine processing point-of-view, it has been argued that mixed content leads to more inefficient parsing—since the underlying XML content is intended to be generated automatically, the readability might be deemed unnecessary. Converting to OOXML would require each instance of text in ODF mixed content segments to be translated into new *w:r* (run) elements.

2. **Referentiality**. Both formats use *references* to styles for span/run formatting. In the case of OOXML, headings are not marked explicitly—rather the value of the *pStyle* attribute would need to be consulted to see how the first paragraph need be formatted. Similarly, italic and bold formatting would need to be derived from the `style-name` attribute for the ODF document. In this respect ODF is more consistent with other text standards, such as HTML and DocBook—headings there are treated as semantic, rather than presentational markers of text, whereas typographical effects (such as font weight and italicization) are matters of style.

3. **Abstraction**. Hyperlink and image data can be easily read off the `href` attribute of anchor and image elements in the ODF document; this could either resolve to an image in the document package, The OOXML document adds an additional layer of abstraction: an `id` attribute refers to a `Relationship` defined elsewhere in the document package, which in turn references the resource—a model defined as part of the OPC, and described more fully above. Moreover the `href` attribute is in fact part of the imported *XLink* schema, which is part of the wider web architecture—its adoption here simplifies processing for systems which already utilise this standard.

4. **Single versus Multiple Methods**. As mentioned in the brief history of the formats above, the OOXML is burdened by compatibility with the voluminous corpus of existing *Microsoft Word* documents. This is evident here in the use of the VML schema—for elements `pict`, `shapetype`, `shape`—rather than the newer DrawingML schema (both of which are part of the OOXML specification). Conversion tools converting to ODF would need to handle the possibility of images using either one of these schemas.

5. **Classificatory versus Attributive**. The terseness of the ODF document leads to a corresponding distinction between the number of elements and attributes in each document. In the case of the ODF document, there are 33 elements and 74 attributes (a ratio of 2.24 attributes per element). In the case of the OOXML document, there are 68 elements and 65 attributes (a ratio of 0.96 attributes per

element)[66]. This suggests that ODF more generally modifies a small number of elements with a large number of attributes; OOXML uses a larger number of elements, with fewer attributes.

6. **Prescriptiveness**. Although this sample document is too small to provide ample evidence, OOXML appears to be more restrictive in what must be stated about a document for it to be handled correctly. The use of additional concepts to specify image and section properties, compared with ODF, tend to confirm this.

Findings—Technical Dimensions of Commensurability

Of the various differences between the two formats, the preceding technical analysis demonstrates a number of salient ones along which they can be said to be, in varying degrees, incommensurable:

1. **Self-contained versus derivative**. The analysis of schemas showed OOXML to be highly self-contained, referencing only the DublinCore metadata standard. ODF, referencing a total of 7 other schemas, is highly derivative.

2. **Abstract versus concrete**. The analysis of package formats showed that in this area at least, OOXML employees a considerably greater level of abstraction to ODF. Similarly the handling of hyperlink and image resources demonstrates a higher degree of abstraction.

3. **Prescriptive versus descriptive**. The analysis of metadata showed OOXML to be less extensible and therefore more prescriptive in orientation. This was reinforced by the high degree of specificity in the handling of image and section information in the document itself.

4. **Verbose versus dense**. In the document analysis, OOXML appeared more verbose both in the quantitative number of elements (68 to 33) and in the complexity of structure. This is due to ODF's use of a mixed content model, permitting elements to contain both child elements and text.

5. **Referential versus in-place**. Both formats use styles extensively to describe how content ought be presented and formatted. However, the orientation is somewhat different; what might be considered structural information (such as headings) must be inferred from the style name and properties in OOXML, whereas in ODF, typographical instructions are relegated to style specifications.

6. **Single versus multiple methods**. OOXML permits two separate models to be used for specifying graphical data (DrawingML and VML), whereas ODF uses only one model.

[66]The following XPath expressions have been used to count element and attributes respectively: `count(//*)` and `count(//@*)`

Table 8.9: Technical Factors

Feature	**ODF**	**OOXML**
Derivative?	High	Low
Abstract?	Low	Medium
Prescriptive?	Medium	High
Verbose?	Low	High
Referential?	Medium	High
Multiple methods?	Low	Medium
Classificatory?	Low	High

7. **Classificatory versus attributive**. ODF uses a smaller range of classifications for content elements, preferring to use attributes to specify styles and other features.

Table 8.9 summarises these differences, providing a rating of Low, Medium or High against these factors. Several other studies of the formats mention these differences, and suggest others:

1. **Mathematical notation and formulae**. OOXML supplies a full notational and formulaic syntax; ODF currently uses MathML for notation, but does not specify which spreadsheet formulae are to be supported[67] (the latest draft of ODF attempts to remedy this[68]).

2. **Use of incomplete and undocumented features**. OOXML has numerous obscure attributes, such as "autoSpaceLikeWord95". It is not clear how applications other than *Microsoft Office* are meant to handle such features[69].

3. **Similar style**. In addition to re-using standards, ODF also uses similar element names and constructs to other standard mark-up languages such as HTML, lowering the learning curve for engineers using the standard[70].

4. **Terse element names**. OOXML uses a highly concise set of element names, which make the XML document contents difficult for human readers[71].

5. **Internal conceptual re-use**. OOXML has separate definition for word-processing and spreadsheet tables, whereas ODF defines a common table model throughout[72].

6. **Idiosyncratic data definitions**. OOXML uses internal representations for dates, colours, language codes and paper sizes, whereas ODF uses ISO and W3C standards for these definitions (Ditch, 2007).

[67] Ditch (2007).
[68] Durusau and Brauer (2007).
[69] Ditch (2007).
[70] Carrera et al. (2005).
[71] Weir (2006); Macnaghten (2007).
[72] Macnaghten (2007).

Some care needs to be taken in the inferences made from these observations. While they appear to cast OOXML in a somewhat negative light, there are important design and technical considerations which motivate particular differences. For instance, the terse syntax and lack of mixed content appear to be designed for improved performance opening and saving documents[73]. Many other differences are directed towards supporting the very large existing corpus of *Microsoft Office* documents—an obvious goal behind OOXML. This goal mandates awkward compromises: bugs or idiosyncratic features introduced by *Microsoft Word 95* need to continue to be supported within the OOXML specification, for example. The divergent design objectives help explain away the technical differences; but given the two formats were developed in full view of one another[74], what in turn can explain the differences in these objectives? To help answer that, the analysis now turns towards a recent, and fascinating, part of the history in which these formats emerge—specifically, the attempt to ratify OOXML as an ISO/IEC standard.

8.2.3 A Game of Standards—Sociological Analysis

The brief history of document formats came to a close with mention of Microsoft's attempt to have the Open Office XML specification ratified as an ISO/IEC standard, having first gained approval of the Ecma International standards group in 2006. The current section picks up the thread of this story. Unlike the preceding history and technical commentary, analysis of recent events proceeds on shifting ground—given the publicity surrounding the controversy, each week during the period covered—from late 2006 through to early 2008—has produced a fecund and prolix amount of event and commentary. Moreover, many of the intricacies of the controversy lie hidden behind corporate strategic and standard committee meetings—since the analysis draws only on materials evident in the public record, it is necessarily partial and speculative. As a means of reducing this complexity from an analytical standpoint, the controversy is described through a range of *gaming* metaphors. This metaphorical scheme is fortuitous in two key respects: firstly, the rhetoric of games is pervasive in the language of the technology industry generally ("pure *play*", "company *strategy*", "zero sum *game*" are some examples), and this rhetoric has been particularly prevalent here; secondly, the theoretical rubric of commensurability adopted here itself leans on similar tropes—for instance, "language games" (Wittgenstein) and "score-keeping" (Brandom). For a large and complex case study, with intersecting parties and overlapping interests, the language of games can be useful in simplifying and to a limited extent rationalising a complex set of events. Adopting this scheme is therefore useful in simplifying the complex set of events involved in the controversy, and in drawing out the key strategies, players and pay-offs.

What should a game-theoretic analysis of a controversy like this do? As a min-

[73] Ou (2007).
[74] Jones (2007).

imum, it ought to account for the behaviours of a group of social actors or players in a given situation. Frequently, game theory makes an implicit assumption—that players behave rationally, that they perform actions to maximise their pay-offs and achieve the best outcome at the end of the game given the information available to them. Acting otherwise is a mistake, a "bad move". Game theory is usually applied to counter-factual or "what-if" scenarios, but is often also applied to explain past behaviour (Smith and Varese, 2001). In most real-world situations, outside of modelling environments, the factorial explosion of players, moves, information, pay-offs and strategies quickly exhausts human comprehension. Equally, when describing past behaviour, clearly players do not always behave rationally, at least under neo-classical economic terms. The game-theoretic analysis is therefore best treated as a *heuristic model* of the situation—a plausible account of why the situation has emerged as it has.

A social game of the kind examined here typically has a number of common elements:

- Outcomes (possible end states of the game)
- The game environment (situational context or setting in which the game is played)
- Rules
- Players
- Pay-offs (what players have to gain or lose)
- Moves (actions and events made in the game)
- Strategies (designs directed towards particular outcomes, which in turn motivate the moves made)

Game theory traditionally formalises these elements to varying degrees of complexity (see for instance the game theoretic study on the Mafia by (Smith and Varese, 2001), and on Rawlsian distributive justice (Swope et al., 2008). Here the intention is to provide an exploratory rather than a predictive model of the situation, so mathematical modelling is not applied. Stripped of formalism, the method of analysis has considerable similarity to Lyotard's discussion of language games (Lyotard, 1984), Actor-Network Theory studies (Latour, 1993; Law, 1992), Bourdieu's cultural models (Bourdieu, 1990) and "thick description" styles of anthropology (Geertz, 2005). As some of these approaches also do, the study presumes a structural set of relations between parts of the game, as the figure 8.2 illustrates.

Outcomes

Given the debate concerns a rivalry between two different formats, the game produces four possible outcomes:

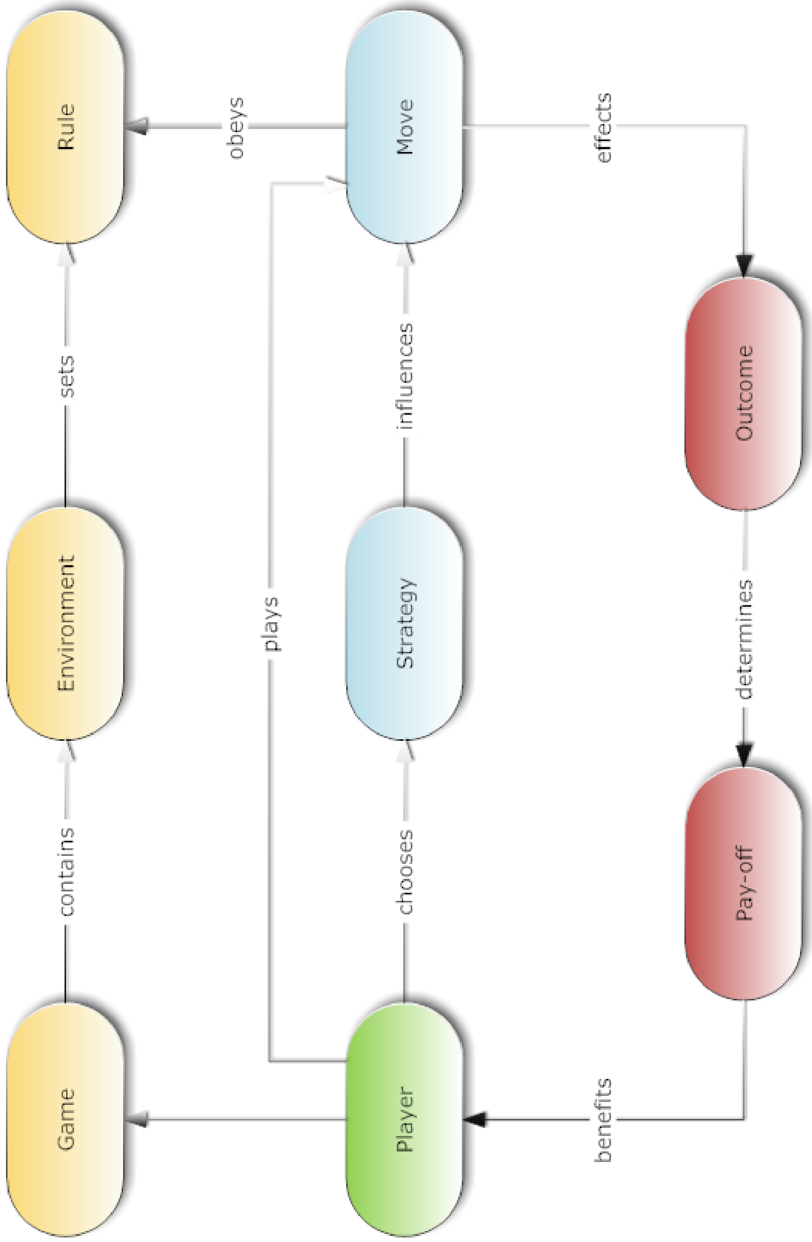

Figure 8.2: Model of Standardisation Game

1. *Pro-ODF*. The ODF standard eventually eclipses OOXML as the dominant document format, and Microsoft is coerced into compliance with ODF—or risk market share diminution.

2. *Pro-OOXML*. OOXML is established as a *de facto*, and eventually, *de jure* standard, and ODF falls into obscurity, or at best occupies a niche market position.

3. *Neutral—Both*. Both ODF and OOXML become widely accepted as document formats. Organisations are then faced with important policy and procurement decisions.

4. *Neutral—Neither*. Neither ODF nor OOXML receive much adoption, due to some kind of paradigm shift in technology. For example HTML, already the standard for web documents, is extended to support the kind of constructs required in the office software market (Google Docs is perhaps the most advanced example of an office software suite using HTML).

Several comments can be made about this description of outcomes:

- In the event that the outcome favours at most *one* of the formats—in other words, one of the outcomes 1, 2 or 4 eventuates—the question of commensurability between the formats is, for all practical purposes, irrelevant. In the event that both formats achieve some measure of success, as in outcome 3, commensurability remains an abiding problem in both the technical and sociological dimensions explored here.

- Each of these outcomes has its proponents, but not always in clear-cut form. For example, various government positions seem to indicate support for the *Pro-ODF* position, but on balance their position would be better characterised as *Neutral—Both*.

Rules

The game is governed by three kinds of rules: those regulating the ISO standards process, those regulating the behaviour of particular players, and those artificially induced by the game situation itself.

ISO Rules
The ISO/IEC Joint Technical Committee (JTC1) oversees standards relating to Information Technology[75], and was responsible for handling the ratification of OOXML. A series of directives stipulate how the JTC1 prepares, adopts and maintains international standards generally. These directives cover:

[75] ISO/IEC (2004).

- The JTC1 organisation (includes various groups: Subcommittees (SC) and Working Groups (WG)) itself;
- Membership types (includes Participating, Observing and Liaison Members)—members must be "National Bodies", usually national standards bodies, such as ANSI (US) and Standards Australia;
- Administrative structures;
- Officers;
- Meeting arrangements;
- Voting procedures and appeals;
- Preparation and adoption of standards (includes "Normal Processing" and "Fast-Track Processing"—the latter can hasten adoption for "existing standards" ratified by other standards bodies);
- Other administrative details and annexes[76].

In addition, the general process for standards approval under the Fast-Track process is:

1. A standards organisation (such as Ecma) submits an existing standard to the ISO/IEC JTC1.
2. A Subcommittee (such as SC34) is set up to process the standard.
3. An individual is nominated as the Project Editor.
4. National Bodies review the proposed standard over a 30 day period, and submit comments related to "perceived contradictions with other standards or approved projects of JTC1, ISO or IEC".
5. The JTC1 Secretariat assesses any such contradictions, and may respond with a set of dispositions to the National Bodies.
6. The National Bodies must vote on the standard within another five month period. Two-thirds of the Participating Members must approve the standard, and no more than one quarter of the National Bodies must disapprove.
7. If the standard is not approved, a Ballot Resolution Meeting (BRM) is scheduled, and convenor appointed. Further dispositions may be submitted in repones to National Body comments attending their vote.
8. If the resolution meeting is unsuccessful, National Bodies are required to submit a second and final vote, after which the standard is either approved or disapproved.

[76] ISO/IEC (2004).

9. If approved, the JTC1 assumes responsibility for the standard's ongoing maintenance[77].

Player Rules
Different players must obey rules particular to their types. For instance, public companies are obligated to obey various corporate codes of conduct, as well as of course state, national and international laws, while simultaneously delivering returns to their shareholders; governments are obligated to acts in their constituents' interests; standards organisations ought obey rules stipulated in organisational regulations, charters and directives; and individuals and consultancies are frequently beholden to employers and contractors who pay them.

Game-Specific Rules
The game itself introduces particular rules. These can be stated as follows (key game-theoretic terms are emphasised):

1. There is no independent arbiter of success in the game. At best various metrics (market share, revenue, total number of users / licenses, number of countries adopting one or another standard, as well as various non-economic metrics) can be used as indicative measures.

2. The game has more than two players. In game theoretic terms, it is an *n-person game*.

3. It is possible to have more than one "winner", and even apparently contradictory outcomes (i.e. both OOXML and ODF can experience increased adoption over the course of the game). In other words, the game is not necessarily *zero sum*.

4. As a corollary of the above rule, pay-offs are not *symmetric*—one player's loss is not necessarily another's reciprocal gain.

5. Players have *imperfect* information.

6. The game can be *cooperative* or *non-cooperative* at different phases—that is, players may choose to share or withhold information from other players.

7. The game has both *simultaneous* and *sequential* aspects. For example, the ISO process clearly requires a strict ordering of events; but company press releases, blog posts and the like are not contingent upon other moves being made.

8. Player alignment can naturally change through the course of the game. National Bodies can change votes; companies and individuals can switch allegiances. A corollary of this is that *mixed strategies* are permitted—i.e. a player can adopt different strategies contingent upon other moves made in the game.

[77] ISO/IEC (2004).

Players

As might be expected, the list of players in a debate of global proportions is large. Table 8.10 lists only the key ones here. Included below is a statement regarding the apparent *desired outcome* for each of the players. This is at best indicative, and is further complicated by, in several cases, the changing positions and dynamic strategies adopted by different players over the period under consideration.

Stakes and Pay-offs

The main stakes and pay-offs of the game are:

- *Economic*—protection or increase of market share, revenue and profit in software licenses and service provision; reduction costs of document creation and management; opportunities for consultancy and employment relating to document management; increased advertising revenue due to public interest in the controversy.
- *Political*—satisfaction of constituents' needs for long-term document retention; persuasion of governments and industry bodies regarding format standardisation; influence on policy; reduction of anti-competitive corporate practices.
- *Legal*—avoidance of potential anti-competitive legislation; compliance with governmental policies concerning document formats; concern over copyright and patent infringement.
- *Social*—improved compliance of documents with accessibility guidelines and policies; reduction of "digital divide" through promotion of open document formats (with available open source software for reading and writing documents); increased credibility, public profile, publicity and recognition through participation in the controversy.
- *Technical*—improved interoperability with other systems; greater critical review through transparency of formats; backward compatibility with legacy documents; improved performance; accessibility support; product innovation.

In practice these motivations are often mixed, undisclosed, or, where evident, seemingly contradictory. Table 8.11 lists the stakes or pay-offs of five kinds of "players" in the standardisation game above: corporations, governments, standards bodies,

[a] Microsoft's own position is somewhat ambivalent—in certain contexts highlighting the deficiencies of ODF relative to OOXML, while elsewhere arguing that both format can and should co-exist. See further discussion below.

[b] It should be noted that unlike ISO, which is comprised of government members, OASIS, ECMA and W3C are *consortia* bodies, with membership including individuals and organisations. It is not unusual for companies to be members of more than one such group—for example, Microsoft is a member of all four standards bodies.

Table 8.10: Key Players

Name	*Type*	*Desired Outcome*
Microsoft	Company	Pro-OOXML / Neutral—Both[a]
Sun	Company	Pro-ODF
IBM	Company	Pro-ODF
Novell	Company	Neutral—Both
Google	Company	Pro-ODF
Corel	Company	Pro-ODF
EU	Government	Pro-ODF / Neutral—Both
National Governments	Government	Mixed
National Bodies	Standards Organisation	Mixed
ISO	Standards Organisation	Neutral—Both
OASIS[b]	Standards Organisation	Pro-ODF
ECMA[b]	Standards Organisation	Pro-OOXML
W3C[b]	Standards Organisation	Neutral—Both
Open Document Foundation	Community/Advocacy Group	Neutral—Neither
Open Document Fellowship	Community/Advocacy Group	Pro-ODF
ODF Alliance	Community/Advocacy Group	Pro-ODF
GNOME Foundation	Community/Advocacy Group	Neutral—Both
OpenXML Community	Community/Advocacy Group	Pro-OOXML
Valoris	Consultancy	Pro-ODF
The Burton Group	Consultancy	Pro-OOXML

community and advocacy groups, and consultants, as well as those of two other less identifiable and amorphous groups: the media, and individual commentators.

Table 8.11: Stakes and pay-offs

	Economic	Political	Legal	Social	Technical
Corporations	- Market share, revenue and income - Flow-on sales (so-called "platform play") - Flow-on benefits in core businesses (software, hardware, services, advertising)	- Influence on corporate and government policy - Alliances with other IT industry partners - Credibility in government markets	- Avoidance of anti-competitive prosecution	- Increased publicity	- Improved product development - Backward compatibility - Performance
Governments	- Reduction in costs - Vendor neutrality	- Long-term document preservation	- Development of policy and law relating to electronic documents	- Accessibility	- System interoperability
Community and advocacy groups	- Consultancy revenue - Lower costs	- Influence on corporate and government policy - Alliances with IT industry partners		- Public recognition - Community interests (accessibility)	- System interoperability

Table 8.11: Stakes and pay-offs

	Economic	Political	Legal	Social	Technical
Standards bodies	N/A	- Satisfaction of members' objectives	- Compliance with internal policies and guidelines		- Development of robust technical standards
Consultancies	- Consultancy revenue	- Influence on corporate and government policy - Alliances with IT industry partners			
Media	- Advertising revenue	- Influence on corporate and government policy		- Provision of news and opinion to the public	
Individuals	- Consultancy revenue - Employment			- Public recognition	

In addition there are specific pay-offs which can tied to particular players. In the case of economic pay-offs, this is most noticeable for the corporations involved in the game. Table 8.12 indicates the financial concerns of the major companies, and in particular the available figures for market share, revenues, profits and number of end-users of office software. All of the following companies are US public companies; financial results have been obtained via their respective SEC filings as of the 28th of February 2008.

Table 8.12: Economic stakes

Company	*Total Market Capitalisation*[a]	Economic stakes	Suite	*Market Share*[b]	*Quarterly Revenue*[c]	*Quarterly Gross Profit*[c]	*# of Users*
Microsoft	$263.02B	Erosion of market-share and profits; Threat of penalties, anti-consumer and anti-competitive lawsuits; Risk to profit in related business divisions (Windows; Server; Online)	*Microsoft Office*	90% +	$4,814M	$3,140M	500 million
Sun Microsystems	$14.03B	Servers (hardware), software & services revenue	StarOffice (OpenOffice)	6-20%[d]	Unknown	Unknown	100 million[d]
IBM	$160.48B	Servers (hardware), software & services revenue	Lotus Symphony (OpenOffice)	Unknown	Unknown	Unknown	Unknown
Google	$148.18B	Advertising revenue	Google Apps	Unknown	Unknown	Unknown	Unknown

Table 8.12: Economic stakes

Company	*Total Market Capitalisation*[a]	Economic stakes	Suite	*Market Share*[b]	*Quarterly Revenue*[c]	*Quarterly Gross Profit*[c]	*# of Users*
Novell	$2.38B	Software & services revenue; Microsoft incentives	Novell OpenOffice	Unknown	Unknown	Unknown	Unknown
Corel	$250.78M	Software revenue	WordPerfect Office Suite	Unknown	Unknown	Unknown	Unknown

[a] Market capitalisation figures taken from Google Finance, on the 28th of February, 2008 (Google, 2008a).

[b] Market share is notoriously hard to quantify in software. Many users frequently use multiple office suites in different situations (work or home for instance), so market share figures are not exclusionary—total market share figures can be in excess of 100%.

[c] Figures stated for quarter October-December 2007, quoted in millions USD. All figures taken from company SEC filings.

[d] The 6-20% figure is based on total estimated *OpenOffice* downloads (IBM's Lotus Symphony is not included) and various analyst report between 2003 and 2005 (OpenOffice.org, 2008).

The stakes for other parties should not be ignored. In particular governments have increasingly proposed policy documents, roadmaps and reports recommending interoperable document frameworks. Fore example, IDABC (Interoperable Delivery of European eGovernment Services to public Administrations, Businesses and Citizens), a branch of the European Commission, commissioned the influential Valoris report advocating ODF adoption in 2003 (Valoris, 2003). In 2004, it followed up by issuing the *European Interoperability Framework for Pan-European eGovernment Services*, which listed eight key principles for the promotion of interoperability:

- Accessibility
- Multilingualism
- Security
- Privacy
- Subsidiarity
- Use of Open Standards
- Access the benefits of Open Source Software
- Use of Multilateral Solutions[78]

Similar statements of principles can be found in numerous government and pan-government interoperability reports endorsing open standards[79]. Nor are governments at a local level unaware of the patent cost benefits of adopting open source software and open standards. A total cost of ownership analysis by the Government of Delhi demonstrated a cost saving of $5.3 million USD over five years in migrating from *Microsoft Office* to *OpenOffice*—with additional savings to be gained in simplifying software procurement and deployment processes[80]. These examples are merely representative of the vast, complex and highly lucrative global public-sector market for which document software vendors vie for tenders. To be sure, the private sector has equivalent commercial appeal—but national governments are not merely passive consumers of technology product; they also define the regulatory environment in which vendors operate. Their key role as ISO National Body voting members moreover ultimately determines the outcome for this game, and thus have tremendous influence over the pay-offs for the corporate players.

[78] IDABC (2004).

[79] Open ePolicy Group (2005); RSA Government IT Officers Council (2007); Australian Government Information Management Office (2005).

[80] Dass et al. (2006).

The Game Environment

The controversy itself has been played across the globe, in a range of both online and offline arenas. The ISO ratification process has been conducted under usual ISO guidelines, which stipulate confidentiality, and thus a significant dimension of the debate has been unavailable for analysis. However, this controversy shows to an extraordinary degree the extent to which corporate strategy is now played out across a host of online avenues—corporate and private websites, press releases, analyst reports, blogs, Wikipedia entries, media outlets, mailing lists and online forums, white papers, academic articles, as well as official specifications, responses, updates, memoranda and corrections from the standards committees themselves. Collectively these texts, released into the public domain, form a kind of rich, intertextual web through which the shifting motivations, concerns and moves of the various players can be at least dimly discerned. The number of players and the volume of documents collated in a relatively short time are sizeable, as the following examples indicate:

- The ISO process itself involves 40 member countries, with 120 individuals. Each are entitled to offer comment on proposed standards; in this particular case, many chose to do so. The formal submission for OOXML raised a total of 3,522 comments in response; even Microsoft employees were "impressed" (Lai, E., 2007).
- The OpenDocument Format is now in the draft stages of its 3rd specification (version 1.2)—around 920 pages.
- The Office Open XML specification dwarves this, however—it consists of 6,000 pages. Suggested revisions, responding to comments from the National Bodies participating in the ISO process, stand at another 2,300 pages.
- There are at least two dozen separate blogs following the debate, authored in the main by employees of Microsoft, Sun and IBM, dedicated to the question of document formats. Many are updated several times a week; many more blogs comment on the controversy more irregularly.
- The OpenDocument Format mailing list (there is no equivalent list for OOXML) generates on average 4 messages per day (OpenDocument Fellowship, 2008), which have tended to spike in relation to significant events in the course over the debate.
- Although no stranger to controversy on other topics, Wikipedia articles on ODF and OOXML have been the subject of substantial criticism over editorial bias. Edit history pages show considerable activity over a sustained period.
- Online technology forums and websites are common avenues for commentary. The website Slashdot regularly receives 100-200 comments to any story related to OOXML (orlando, 2008).

As a side note, apart from the fecund and perhaps daunting scope of the debate from the point of view of sociology, these sorts of figures indicate the complexities facing various players of the modern standardisation game. It is hard to imagine even a decade ago any comparable debate being conducted in similar time-frames, with similar scope and stakes, and with a similar volume of documentation to decipher. Regardless of position—whether as a corporate strategist, government policy maker, community advocate, media commentator, software engineer or indeed academic—the volume of documentation is vast. The Internet of course makes the proliferation of public domain documentation possible, but it also introduces new social environmental problems to those playing the game of standardisation. The dilemma can be roughly summarised as: how does one respond to what is always be a situation of incomplete information, knowing that other players have incomplete yet different information, that may nevertheless be of strategic benefit? It is not enough to know "as much as possible" in order to play the game effectively; players must also have the right kind of knowledge—of the document specifications themselves, of the complex workings of standards bodies, of the political dynamics between nations, of the economic allegiances of companies and individuals, and of course, of the latest "state of play", delivered in electronic piece-meal increments throughout the working day. An ideal player in this environment is thus a curious kind of polymath—technically literate, politically astute, attuned to a host of cultural considerations, an assiduous and relentless researcher, capable of both broad overviews and microscopic analysis, and yet, in some cases, a ruthless opponent and zealot believer in the desired outcome. The document format standards debate, conducted at such speed and engaging a myriad of sources, demonstrates just how a global yet strangely disembodied and virtual environment requires the mobilisation of new skills, new sensitivities and perhaps a new subjectivity from its actors.

Finally, there is also an intriguing self-referential dimension to the debate—for where else, other than in the form of electronic documents, is the debate hosted? Indeed the proliferation of document forms, evident in the media analysed here—wikis, blogs, forums, email, forum comments, news articles, financial filings, statistical surveys, academic papers, whitepapers, reports and specifications, all readily accessible online—themselves are testimony to the centrality of the electronic document form in modern discourse, and the importance of standards for accessibility, debate and analysis.

Standardisation in Motion

The introduction to the document format controversy concluded with Microsoft's response to the challenge of the OpenDocument Format (and its implementations, most noticeably *OpenOffice*)—the launch of a rival standard, Office Open XML, ushered through the ECMA consortium. Here the story picks up where that section left off, with a more detailed account of the specific events leading up and including the final decision by the ISO standards group on the fate of OOXML. The account begins with the submission by ECMA of the OOXML specification to ISO on the 20th of December, 2006, and ends with the second ISO ballot vote in March, 2008 (after the first failed in September 2007).

The ECMA International group, having previously approved the Office Open XML specification within its own member group, submitted the specification to the ISO/IEC Joint Technical Committee (JTC) 1 on December 20, 2006. The JTC1 comprises 41 Participating Members, a subset of the total number of ISO National Bodies. The submission was placed under the Fast-Track program, designed for rapid approval of existing standards, under the name of ISO/IEC DIS (Draft International Standard) 29500. An initial review period was conducted over the subsequent 30 days, during which time "perceived contradictions" to the proposal can be made by ISO members. ECMA responded to these comments on February 28, 2007[81], which was followed by a five month "letter ballot" leading up to a vote on September 2nd, 2007. The ISO regulations require a) that no less than 66.6% of the national bodies involved in the JTC itself *approve* the standard and b) that no more than 25% of the total national bodies *disapprove* (vote abstention is permitted)[82]. The vote results, published in early September 2007, registered 53% of the 41 members participating in the JTC approved, while 26% of the 104 ISO members disapproved[83]. This narrow failure led to an announcement by ISO that a Ballot Resolution Meeting (BRM) would be conducted at the ISO headquarters in Geneva, Switzerland, between the 25th and 29th of February, 2008, with the final ballot on OOXML to be held 30 days later on the 29th of March[84]. The BRM is designed for the standard submitter to respond to comments with possible amendments, and for the National Bodies then to vote again on whether the amendments are sufficient to pass the standard.

In addition to the negative vote result, a total of 3,522 comments were raised by the National Body members. The Ecma Technical Committee (TC45), alongside the ISO Project Editor, were tasked with formulating a series of "proposed dispositions"—responses—to these comments. Both comments and dispositions were not subject to public scrutiny, according to ISO directives. Their character can be inferred from a Ecma press release, which outlines several substantive objections, and recommended amendments to the OOXML proposal to incorporate them[85]. These recommendations are not binding upon the specification[86]; however they do provide ISO members with suggested mechanisms for resolving objections at the BRM, in the hope of securing the required number of approval votes.

The major events of the standardisation period can be summarised as follows:

- December 20, 2006—Ecma International submits OOXML to ISO.

[81]Ecma International (2007a).
[82]ISO (2007).
[83]ISO (2007).
[84]ISO (2008a).
[85]Ecma International (2008a).
[86]ODF Alliance (2008a).

- January 19, 2007—Deadline for National Bodies to submit "perceived contradictions".
- February 29, 2007—Ecma International responds to National Body comments; triggers five month ballot.
- September 2, 2007—OOXML narrowly failed to gain approval; National Bodies submit comments with vote.
- January 14, 2008—Ecma International responds to 3,522 comments (reduced to 1,100 after elimination of duplicates) with "proposed dispositions".
- February 25-9, 2008—Ballot Resolution Meeting (BRM). JTC1 members meet in Geneva to attempt resolving the ballot with the aid of the dispositions.
- March 29, 2008—Final vote on OOXML.

The apparent calm of the august and bureaucratic ISO procedures belies the turbulent undercurrents which swept through both the voting arrangements and subsequent preparation for the Ballot Resolution Meeting. During the vote itself, numerous reports surfaced suggesting that Microsoft played a significant, and sometimes insidious role in the deliberations of many national bodies. In Portugal, one participant published transcripts—not independently verified—of discussions within the technical committee preparing its vote. The transcripts has elements of high farce: there is a prolonged conversation about lack of chairs for Sun and IBM representatives; the author himself has problem being heard within a small group of 25 participants; he complains that the committee is stacked with Microsoft affiliates; and finally, in exasperation, suggests if the ODF and OOXML formats are not interoperable, perhaps a *third* standard should be created...[87] The complaint of branch stacking occurs elsewhere: in Sweden, Microsoft partners were introduced at the eleventh hour into the voting group, a breach of voting regulations severe enough to warrant Sweden's vote being recorded as an enforced abstention[88]. Further reports were filed in blogs, open letters and the press outlining purported voting irregularities in Denmark[89], Italy[90], Malaysia[91], the Philippines[92], Switzerland, Germany, the Netherlands, and the US[93]. Another complaint was the ambiguous composition of the National Bodies themselves—although generally represented by standards bodies developed by national governments, they are frequently populated by experts employed by large technology companies, which include industry stalwarts like Microsoft and IBM. Hence there are frequently charges of bias and conflicts of interest against the ISO voting

[87] Seabra (2007).
[88] Haverblad (2007).
[89] Orion (2007).
[90] Updegrove (2007b).
[91] Kit (2007a).
[92] Schestowitz (2008b).
[93] Espiner (2007).

members, as much as against the standard submitters. The claims of infiltration and corruption are as yet uncorroborated, although the EU has recently been considering taking Microsoft to court on the basis of the allegations of intrusion into ISO committees[94]—to add to two other current cases of anti-trust litigation[95]. Soon after the vote, two studies (published online and not peer-reviewed) attempted to demonstrate a significant correlation between, respectively, levels of corruption and GDP, and approval votes from ISO members—in other words, more corrupt and poorer countries were more likely to approve OOXML in the ISO ballot[96]. Such studies, however uncorroborated or patronising, contributed to a perception of significant Microsoft intervention—through economic or other incentives—in those countries' voting procedures.

Many other complaints surfaced around the submission, both during and after the voting process. Many National Bodies complained about the volume of documentation—6,000 pages of specification, 3,500 comments lodged by the voting ISO members, followed by another 2,000 pages of amendments in response to the comments—and the dubious merit of using the "Fast Track" process for such a voluminous standard[97]. Since the initial 30-day review period, considerable attention focussed on whether OOXML was in fact duplicating the existing ISO/IEC 26300 standard—the ODF format[98]. Concerns were also raised over the naming of the specification itself—variously called "Office Open XML" (OOXML) and "Open XML", advocates of OpenDocument Format suggested these were intended to confuse non-specialists, particularly since the largest implementation of ODF had long since—since 2002—been named *OpenOffice*[99]. The ECMA group's legitimacy as a standards body was called also into question—co-authors of the OOXML specification appeared to include only two non-corporate entities, the British Library, and the Library of Congress—and seemed to be little more than an arm's length vehicle for the promotion of Microsoft's fiscal interests[100]. Rumours of Ecma voting membership costing $57K USD reinforced the impression of a closed group of companies "rubber-stamping" each other's standards, rather than subjecting them to due diligence and scrutiny[101].

More indirectly, Microsoft had been accused of both surreptitiously and overtly distorting discussion of OOXML. In January 2007 Rick Jelliffe, a prominent author and developer of XML technologies, was contracted by Microsoft to "provide more balance on Wikipedia concerning ODF/OOXML"[102]. In spite of offering a nuanced defence of his position, a furour immediately erupted—188 comments were posted

[94] Forelle (2007).
[95] European Union - Directorate General Communication (2008).
[96] Puolamäki (2007); Hintjens (2008).
[97] Ecma International (2007a).
[98] Ecma International (2007a).
[99] ODF Alliance (2008a).
[100] Kit (2007b).
[101] Weir (2007).
[102] Jelliffe (2007).

in response to his blog post announcing his acceptance—over the subversion of the (always idealised) independence of Wikipedia content. In a further twist, Standards Australia invited Jelliffe to the Ballot Resolution Meeting a year later[103], raising yet further suspicion[104]. At time of writing, the OOXML Wikipedia entry includes at least 50 discussion entries, the majority concerning various authorial biases around serial edits, corrections and amendments to the article. The following is a short fragment:

> "There is significant criticism to OOXML that is currently not mentioned in the article. There is a single person, User:HAl, that repeatedly removes edits (not even rephrasing them) that he believes are critical to OOXML . . . Simosx 18:33, 2 August 2007 (UTC)
>
> HAI: your name appears frequently in edit wars [debates over Wikipedia entries] and your edits have an indisputable POV [point of view] favouring Microsoft. To avoid having formal complaints tabled against you, please disclose your interest, stake, and/or association with OOXML, its developers, and Microsoft. It is important that we understand why you are rewriting the article in Microsoft's favour so that we can end these edit wars . . . DominusSuus —Preceding unsigned comment added by 99.234.66.219 (talk) 07:26, 4 February 2008 (UTC)
>
> Bla bla. In this case it is not hard to have to reedit the article in favour of Micrsoft [sic] because a lot of edits are made by member with for instance affiliations with the FFII and other organizations that oppose OOXML . . . It would be a whole lot better if the opponents of OOXML and OOXML standardization stayed away from wikipedia trying to influence opinion on the article. hAl (talk) 10:40, 4 February 2008 (UTC)" (Wikipedia, 2008a)

Claims of surreptitious distorting of online content were voiced through other channels. Criticisms were leveled at anonymous so-called "trolling" (posting spurious canned defences or attacks) in response to any negative commentary on technology blogs and forums like *slashdot.org*. In a similar vein, a discussion on the ODF mailing list suggested Microsoft had paid for the term "Open Document" on the Google search engine—designed to confuse searches for OpenDocument Format[105] (in 2008, searches of the term "Open Document", not just the phrase "open document", both presented a sponsored link for "Open XML"[106].

Claims of distortion were also levied at Microsoft around perceived attempts to purchase good press in IT journals and reports. A report released early in 2008 by

[103] Jelliffe (2008).
[104] NoOOXML (2008).
[105] Barrionuevo et al. (2008).
[106] Google (2008b).

the Burton Group advocated use of OOXML over ODF:

> Any organization ... using Microsoft Office applications should plan to exploit OOXML ...
>
> ODF is insufficient for complex real-world enterprise requirements, and it is indirectly controlled by Sun Microsystems, despite also being an ISO standard ... for now ODF should be seen as more of an anti-Microsoft political statement than an objective technology selection[107].

Once this report was released, the ODF Alliance quickly issued a rebuttal, complaining both of a number of technical inaccuracies, and of the timing of the publication, so soon before the ISO delegates were due to meet to vote in the Ballot Resolution Meeting in 2008[108]. This triggered several rounds of call-and-response from various bloggers from both camps, including an insinuation that one of the report's authors, Peter O'Kelly, stood to benefit through indirect remunerations via appearances at Microsoft trade shows[109]. This in turn provoked an angry reaction from O'Kelly, stating that together the authors had interviewed a range of companies in compiling the report, and specifically had refused corrections by Microsoft in order not to impugn their neutrality[110].

In a further move, Novell—an early supporter of ODF—appeared to have been enticed into an equivocal position on formats by Microsoft. It had begun developing an open source converter of ODF documents to OOXML, which implied a significant compromise had been made to the collective goals of a single document standard. This raised the ire of open source advocates, already concerned about the announcement in November 2006 that Microsoft and Novell had entered into a broad-ranging agreement involving technical, legal and marketing co-operation (as part of this agreement, Microsoft had pledged $450 million to be spent on Novell sales, licenses and marketing over five years, and Novell agreed to drop litigation over patent infringement relating to their *WordPerfect* product[111]). This demonstrates the changing dynamics of the game—minor players can re-align their positions if *new* pay-offs are introduced. Microsoft had previously had experience at side-stepping anti-trust accusations by propping up its competition financially, when it invested $150 million USD in Apple[112].

In part to counter the effect of negative perception and press, Microsoft also engaged several of its senior staff to author active blogs on OOXML. This vehicle supplied a far more personal, direct and efficient means of influencing debate than conventional press releases. Met with counter-posts from employees at IBM and Sun,

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[107] O'Kelly and Creese (2008).
[108] ODF Alliance (2008b).
[109] Weir (2008a).
[110] Creese (2008).
[111] Gartner (2006).
[112] Kawamoto et al. (1997).

and a large number of open source and open standard individual advocates, the "blogosphere" provided an effective channel for all parties to disseminate both information and opinion. Moreover the personalised nature of the medium enabled Microsoft—arguably—to sidestep some of the stigma associated with its prior public relations campaigns of "technology evangelism" (described in the historical background section above), by engaging directly with its critics.

Finally, in a series of announcements and updates leading up to the BRM, Microsoft endeavoured to bolster its credentials on the question of openness. In late 2006, it released the "Open Specification Promise", an undertaking "not to assert any Microsoft Necessary Claims" against the development and use of implementation of "Covered Specifications"[113]. OOXML was listed as one of the specifications to be effectively released from patent rights. This was followed by the release of *Microsoft Office* binary formats under the same promise in early 2008[114]. Six days later, and just four days before the BRM was due to convene, a high-powered delegation including the CEO, Steve Ballmer, senior vice-president and general counsel Brad Smith, and Chief Software Architect, Ray Ozzie, announced an astonishing series of "principles" and "actions" to promote interoperability and openness[115]. These included the release—unprecedented for the company—of 30,000 pages of previously closely held technical product documentation. Response was immediate, and tended—predictably—to eulogise or decry the announcement. Critics were inclined to praise the content of the announcement, but treat the *timing* with suspicion—see Updegrove for a useful summary of responses[116]. But in conjunction with the OOXML itself, unquestionably the release of this volume of documentation represented an attempt at least to demonstrate a marked shift from the culture of secrecy and hostility which pervaded the company in previous decade. The presentation itself included the following insightful remark from Ray Ozzie, which points to *structural* conditions in the software industry—rather than individual corporate caprice—for why product *differentiation* precedes format *standardisation*:

> When a new type of product or technology is introduced, vendors tend to focus first and foremost on little more than whether or not their product satisfies an immediate customer need, and in these early stage products innovation tends to trump interoperability, data portability, or any such concerns. But as users put more and more of their data into these products, a new set of issues emerge ... Issues such as document preservation and portability have become vital concerns for customers. Furthermore, as a direct byproduct of the Internet's ubiquity, virtually every system and product nowadays has become interconnected in some way to most everything else. And so interoperability between our systems has also become

[113] Microsoft Corporation (2006).
[114] Microsoft Corporation (2008a).
[115] Microsoft Corporation (2008a).
[116] Updegrove (2008a).

> a vital concern[117].

Interestingly, Andy Updegrove, a Boston-based lawyer advocating for ODF, argued along much the same lines but for the opposing cause: in his view, standardisation was similarly a consequence of gradual industry maturation[118].

Just as Microsoft galvanised the many parts of its formidable public relations machine, defenders of the Open Document format had been equally indefatigable in making the opposing case. Throughout the period under consideration, the ODF mailing list witnessed average traffic of four emails a day—rising in intensity around key events like the ISO ballot result itself. There are several dozen blogs and websites dedicated to commenting upon OOXML and related issues; these link not only to one another, but also frequently with blogs maintained by Microsoft employees. Several of these are deliberately incendiary in name—*BoycottNovell*, *NoOOXML*, *OOXML Hoaxes*—and range from closely detailed technical argument through to extravagant conspiracy theories. In equal measure, ODF proponents engaged in active editing of both OOXML and ODF Wikipedia pages, as well as offering significant counter-commentary on Microsoft employee blogs, forums, and elsewhere.

One curious aspect of the entire controversy is the willingness of individuals and advocacy groups to applaud two other large US corporations—Sun Microsystems and IBM—in their endorsements, promotion and funding of ongoing ODF development. One cynical view from Europe however saw the debate as little more than standard corporate intrigue and posturing—an unexceptional side-effect of capitalist agonistic tendencies, played out on a multi-national stage by US companies predominantly located in California and Seattle. They concluded their review with:

> Some content themselves with shrugging their shoulders and saying "let's leave the wolves to eat among themselves "[119].

Another interesting aspect to the debate were the company personnel involved; while tonally, the comments are frequently bitter and personal, they are somewhat localised to program managers rather than CEO's or other executives. This can perhaps be explained due to the fact that the very same companies also co-operate and partner in other areas, epitomised in the modern neologism of "co-opetition". To that extent, the use of blogging and other informal techniques represent a more risk-adverse strategy than litigation, polemic press releases and CEO-level speeches (which have been common in other IT industry skirmishes[120]). Nevertheless, and discounting the enormous financial results Microsoft continued to draw from sales of its *Microsoft Office* product, IBM and Sun seemed to have comfortably won the public relations battle during the ratification debate—to the extent that many of

[117] Microsoft Corporation (2008a).
[118] Updegrove (2007b).
[119] Gouarné (2007) [my translation]
[120] United States District Court (2002).

the Microsoft public manoeuvres have been considerably defensive. In the lead-up to the Ballot Resolution Meeting in early 2008, Brian Jones, a program manager in Microsoft's Office division complained that Rob Weir, an employee of IBM and co-chair on the OASIS ODF Technical Committee, had been flown to various ISO national body groups in an attempt to lobby against OOXML[121]. Gray Knowlton, a Group Product Manager in the same division, went further, and analysed each of Rob Weir's posts on OOXML, concluding that out of 134 posts, "94 of those posts have a central anti-Open XML and/or anti-Microsoft theme"[122]. That, in Microsoft's view, IBM—not Sun, nor any other parties—seemed to be coordinating the obstruction of the OOXML standardisation process was made clear in an article in the popular technology magazine, ZDNet. Provocatively entitled *Microsoft: IBM masterminded OOXML failure*, it quotes several senior Microsoft employees in a telling series of statements:

> While criticism of Microsoft's efforts to promote the standard has come from a variety of quarters, Microsoft's senior director of XML technology, Jean Paoli, accused IBM of masterminding the attack.
>
> "Let's be very clear," Paoli said. "It has been fostered by a single company — IBM. If it was not for IBM, it would have been business as usual for this standard." ...
>
> Microsoft claims its competitor has since opted for more covert tactics to influence the ISO vote.
>
> Nicos Tsilas, senior director of interoperability and IP policy at Microsoft, said that IBM and the likes of the Free Software Foundation have been lobbying governments to mandate the rival OpenDocument Format (ODF) standard to the exclusion of any other format.
>
> "They have made this a religious and highly political debate," Tsilas said. "They are doing this because it is advancing their business model. Over 50 percent of IBM's revenues come from consulting services." ...
>
> "IBM have asked governments to have an open-source, exclusive purchasing policy," Tsilas said. "Our competitors have targeted this one product — mandating one document format over others to harm Microsoft's profit stream."
>
> "It's a new way to compete," Tsilas said. "They are using government intervention as a way to compete. It's competing through regulation, because you couldn't compete technically."[123]

This fed further claims that Microsoft was simply buying good press, since the author of this article disclosed he was flown from Australia to Redmond at Microsoft's expense. BoycottNovell blogger Roy Schestowitz noted:

[121] Jones (2008a).
[122] Knowlton (2008).
[123] Winterford (2008).

> So there. Here you have another bias article that was composed after a seemingly-free trip to Redmond, WA where Microsoft partners delivered grossly-biased talks[124].

Another Microsoft blogger, Steve McGibbon, elsewhere pointed to the strategic use Sun makes of standards as a means of achieving commercial goals:

> Interesting May 2006 article on IEC's website that I haven't seen before in which Michelle Aden, Sun's "Standards Strategy Ambassador for the Chief Technologists's [sic] Office" explains how standards are:-
>
> > . . . a "strategic weapon" in her company's arsenal. "Those who prepare standards," she explains, "have a competitive advantage because their ideas are being standardized."[125]

The involvement of Sun Microsystems and IBM has not been without critique from other quarters either. A small advocacy group by the name of the Open Document Foundation, comprising of three individuals based in the United States, had in the formative years of ODF been loud supporters of the standard. In mid-2007 the group—while still retaining its name—announced publicly it no longer supported the OpenDocument Format, claiming it had been co-opted for purely commercial ends by Sun Microsystems. Instead the group advocated yet another standard, the Compound Document Format (CDF), put forward by the W3C. At the time of writing, CDF remains a format predominantly designed for use on small devices such as mobile phones—no major office software package currently provides support for it. Thus the decision by the Open Document Foundation appeared considerably eccentric, and led in turn to a long series of heated exchanges on the ODF mailing list. Eventually the Open Document Foundation group decided to disband, foregoing the name since this would lead only to greater confusion. Nevertheless its participants, in their various blogs, remained sceptical of Sun's active steerage of the ODF format as much as of Microsoft's promotion of OOXML, and instead continued to advocate various hybridised forms of HTML as the superior alternative to both formats—an example of active militancy for an overall outcome to the controversy of *Neutral—Neither*.

In late 2007 a separate debate flared up on the ODF mailing list, this time concerning efforts by a former Novell employee, Jody Goldberg, to support OOXML documents in the open source *Gnumeric* program (affiliated with *Gnome*, a popular desktop environment for the Linux operating system). Seen as undermining the spirit of open source and open standards generally, and the ODF particularly, Goldberg and the Gnome Foundation Director, Jeff Waugh, defended their position regarding the need to ensure interoperability with *Microsoft Office* for their users. The discussion ended with a stalemate, which suggested at least a lack of willingness on the part of

[124] Schestowitz (2008a).
[125] McGibbon (2008a).

ODF advocates to appreciate the pragmatic aims of other open source groups, who were willing to accept the interim *Neutral—Both* predicament.

In the final lead up to the Ballot Resolution Meeting, the OpenForum Europe—another loose affiliation of companies and individuals—had been accused both by Microsoft and by the BRM convenor, Alan Brown, of holding a rival conference coinciding with the BRM itself, and operating in the same convention centre in Geneva[126]. This second event has been viewed as an intentional disruption to the BRM, staged for political purposes to confuse and provoke the BRM delegates—all the more so when it became clear that keynote addresses were to be delivered by noted opponents of OOXML, and that significant representatives from Google (Vint Cerf—a celebrated pioneer of the Internet) and IBM (Bob Sutor, another vocal critic of OOXML) would also be present. In the words of Alan Brown:

> It seems the OpenForum Europe is organising a meeting to coincide with the BRM: same time, same venue. It's not clear from the announcement what time of day this seminar is scheduled to take place, though an invitation is issued to BRM attendees. I will be disappointed if those involved in this event expect BRM delegates abandon their work in session to attend this meeting, as that can only diminish legitimate participation in this important ballot resolution process[127].

Hence at least two notable "moves" can be identified in the lead-up to the decisive end-game of the controversy: Microsoft announcing a major new company-wide change towards interoperability and openness just prior to the BRM; and Google and IBM helping to organise a disruptive coinciding event. But before turning to the outcome, it is worth examining an intriguing facet of the debate which revolves around the very question of commensurability itself.

"Harmonisation or Unification"—the Sub-game of Commensurability

One of the major bones of contention in the controversy is the need for a second standard at all (see in particular the comments of twelve National Bodies in the comments to the 30-day review, along with the Ecma response[128]). The ISO guidelines specifically rule out having two standards with significant overlapping areas—which naturally ODF and OOXML exhibit. Microsoft have claimed the need for OOXML on the basis that the ODF misses out substantial portions of what a *Microsoft Office* document needs to capture—the Burton report also corroborates this argument. The question then arises: to what extent can the ODF be extended to support these portions, without requiring an entirely new format? In the jargon of document formats, this is a problem of harmonisation. Naturally enough, ODF proponents argue this is

[126] Brown (2008a).
[127] Brown (2008a).
[128] Ecma International (2007a).

feasible; OOXML proponents suggest that it is exceedingly difficult. Assessment of the commensurability of the formats is therefore a point of distinction between the two factions: if they are commensurable, then only one of the formats deserves to be standardised (with ODF being the fortuitous incumbent according to ISO rules); if they are *in*commensurable, there is sufficient justification for both to be adopted (clearly Microsoft's position).

Put in stark terms, the argument for two document standards emphasises the different goals of each standard. In part the argument puts *in extremis* the case made more contingently in this study—there can be significant and irreconciliable underlying differences between two formal knowledge or information schemas, at least for given situations and purposes. From the *Ecma Response Document*, quoted by Brian Jones:

> First, while both formats share the high-level goal, to represent documents, presentations, and spreadsheets in XML, their low-level goals differ fundamentally. OpenXML is designed to represent the existing corpus of documents faithfully, even if that means preserving idiosyncrasies that one might not choose given the luxury of starting from a clean slate. In the ODF design, compatibility with and preservation of existing Office documents were not goals. Each set of goals is valuable; sacrificing either at the expense of the other may not be in the best interest of users.
>
> Second, the resulting differences are not merely variances in scope that could be resolved by adding capabilities to one or the other. They are structural and architectural in nature. Where functionality overlaps, the corresponding elements nonetheless differ in precise meaning, usage, capabilities, options, and interaction with other elements. Even more importantly, the corresponding elements do not exist in isolation, but are components of whole document models, with different rules and constraints . . . The resulting variations are not merely cosmetic. They compound to create qualitative disparities that, although perfectly acceptable for much of the user base, can be significant for organizations that require high fidelity in layout, content, or editability[129].

The question of harmonisation is thus one for further detailed analysis, and out-of-scope for OOXML itself:

> Harmonization would require functional changes to two International Standards and would fall under the JTC 1 procedures for new work within SC34 and could be done in the future[130].

The argument for a single standard states that regardless of purposes and goals, having two standards is simply contradictory and confusing for the majority of docu-

[129] Jones (2008a).
[130] Jones (2008a).

ment users. Why not then have the necessary features of OOXML brought back into ODF as extensions of some sort? A frequently quoted maxim of this line of thought is provided by Tim Bray, an author of the original XML specification, a Sun employee, and as of early January 2008 a member of the Canadian Technical Committee on OOXML :

> I still think OOXML is totally bogus; ECMA shouldn't have gone near it and neither should ISO. The world does *not* need two ways to say "This paragraph is in 12-point Arial with 1.2em leading and ragged-right justification". As I argued in 2005, if you want to capture MS-Office-specific semantics (not a bad thing in principle) the right way to do it is a namespaced layer on top of ODF[131].

This position is echoed by Rob Weir from IBM:

> A look at OpenOffice and Microsoft Office shows a huge degree of functional overlap. Harmonization starts from looking at this functional overlap—and there is a significant, perhaps 90%+ area where they do overlap—and expresses the functional overlap identically, using the same xml schema. In other words, harmonization identifies the commonalities at the functional level and finds a common representation for that commonality[132].

In principle the difference between these two positions is one of degree rather than kind—the "unification" argument states the overlap between the formats is sufficient for them to be unified; the "harmonization" argument states the overlap is enough to permit translation, but differing overall design goals and architectural models cause irreconciliable semantic differences[133]. But the distinction is more subtle. On the one hand the Ecma response is that the two formats differ markedly in technical features—they are *technically* incommensurable—while in a societal sense there is no contradiction in their co-existence—they are *socially* commensurable. On the other hand, critics of this response argue the formats themselves are *technically* commensurable—the missing features of OOXML can be added on as an overlay to ODF—but socially *incommensurable*—that it is indeed contradictory, as several National Body objections suggested, to maintain two substantially overlapping standards. In this view, *whatever* the technical differences they ought to be coerced into a common document model. Moreover, any support for two standards so closely aligned in function is a ruse—the *Neutral—Both* position is a convenient diplomatic stance from which to militate for the *Pro-OOXML* outcome[134]. So the very views on the question of commensurability stand in juxtaposition—split down two different dimensions—and *this* difference itself begs to be included into any commensurability assessment.

[131] Bray (2008a).
[132] Weir (2008b).
[133] Hamilton (2008); Gray (2008).
[134] Jones (2008c).

In early 2008, a German DIN (German Institute for Standardisation) Working Group group was set up to respond to this dilemma[135]. A brief and substantially incomplete draft report was issued in March 2008, highlighting specific features of the two formats and indicating whether these features were translatable on a scale of "High", "Medium" or "Low"[136]. At time of writing, there no updates to this report—no doubt due to the fact that as suggested earlier, a systematic review of harmonisation between the two formats is a significant undertaking in itself. From the point of view of reaching a voting results, suffice to say advocates on both sides found plenty of encouragement for their position from timely publication of the report.

8.2.4 End-Game? BRM and the Final Vote Result

Over the course of 2008, the controversy did not so much end as peter out—although not without some surprising twists. The final BRM vote failed to provide a clear-cut result—with both sides calling victory. In a frenetic 4 day session, from the 25th to the 28th of February, the Ballot Resolution Meeting attempted to sift through an overwhelming number of revisions and comments on the original proposal[137]. The majority of these—over 80%—were necessarily ignored or cursorily dealt with, to the dismay of many attendees and commentators[138]. The outcome of the meeting was a further 30-day voting period, in which members could agree or disagree with the revisions to the OOXML proposal—effectively, a successful vote on the revisions would overturn the previously unsuccessful vote on the proposal itself. Blogging and mailing list activity spiked over the month of March, as speculation mounted over the direction ISO voting members would take.

By the 30th of March, a number of previously dissenting votes were now agreed to the revisions, ushering in DIS 29500 as a new ISO standard. On April the 2nd, the ISO committee issued a press release tersely announcing the approval: "ISO/IEC DIS 29500, *Information technology—Office Open XML file formats*, has received the necessary number of votes for approval as an ISO/IEC International Standard"[139]. As the press release further noted, under ISO regulations at least 2/3 of the participating national body votes were positive in favour of the standard, while no more than 25% of the total national body votes were negative (the actual numbers were 75% positive, and 14% negative, respectively)[140]. Microsoft had issued a self-congratulatory press release a day earlier—ironically, on April Fool's Day—and shortly after, numerous bloggers active in the lead-up to the vote were busy dissecting the results[141]. In the months that followed, four countries (Brazil, India, South Africa, Venezuela) appealed the decision, on varied grounds:

[135] Deutsches Institut für Normung (2007).
[136] Deutsches Institut für Normung (2008).
[137] Hogarth (2008).
[138] Bray (2008b); Hogarth (2008); Silva (2008); Updegrove (2008b).
[139] ISO (2008b).
[140] ISO (2008b).
[141] Microsoft Corporation (2008c).

- Failure of the proposal to address contradictions.
- Failure of the proposal to meet ISO guidelines and directives.
- Failure of ISO to publish BRM decisions and other documents.
- Failure of ISO to protect the voting process from interference by multinational corporations.
- Failure of ISO to deal with the contradiction of approving a very sizeable specification within the scope of the fast-track process.

Confidential details of the objections—and the internal recommendations to the ISO Technical Management Board by the CEO's of ISO and IEC respectively to ignore the objections—were obtained independently by Pamela Jones (author of the Groklaw blog)[142] and Andy Updegrove (author of the Consortium.info blog) in early July[143]. While revealing, these objections did not result in further action being taken—the appeals were quietly rejected by yet another round of voting in mid August[144].

Finally, in November 2008 the complete and amended ISO/IEC 29500:2008 specification was published and made freely available[145]. The set of four documents comprising the first version of the standard ran at 7,234 pages, not including associated technical electronic inserts. As of April 2009, no software—including any edition of *Microsoft Office*—yet supports the ISO standard, though Microsoft have announced the next edition (Office 14) will be compliant[146].

The same press release, issued in May 2008, makes a far more remarkable admission, in the context of the then-recent victory of OOXML—that an update the *current* edition of *Microsoft Office* would add support for OpenDocument Format. Couched within general language of "expanding the range of document formats", this announcement has led to the perplexing situation that ODF—not OOXML, at least in its ISO-ratified form—is supported by the current flagship product of its apparent arch nemesis[147]. Of course, a variant of OOXML, notably more promiscuous over the course of 2008 and 2009 by its ".docx" file extension, remains the *default* format of *Microsoft Office*. Nonetheless, this and a series of related moves by the corporate giant—to become a member of the OASIS ODF Technical Committee[148], to fund Apache, a loose consortium devoted to open source software, to extend its Open Specification Promise to include software developed under a GNU Public License (GPL)[149], and to contribute to and release a number of open source projects—at the very least complicated the simplistic characterisation of Microsoft as solitary villain

[142] Jones (2008d).
[143] Updegrove (2008c).
[144] Updegrove (2008d).
[145] ISO (2008d).
[146] Microsoft Corporation (2008d).
[147] Microsoft Corporation (2008d).
[148] McGibbon (2008b).
[149] Microsoft Corporation (2008e); Jones (2008e).

of the document formats narrative. It suggests also that both sides of the controversy had made substantial progress. Microsoft finally saw its rival format standardised; Sun and other competitors witnessed, at least at face value, a more conciliatory opponent, now working through many of the same channels towards document interoperability.

The actual outcomes are of course more difficult to decipher. One Microsoft blogger noted in relation to the support for ODF, "[OpenXML & ODF] never was a zero sum game—it was always about customers winning"[150]. A more adequate characterisation of the controversy would point to a more complex series of stakes and pay-offs. Certainly the ISO organisation itself has had to defend itself against a highly public and critical campaign—a series of press releases, and a long interview with the CEO, Alan Bryden, in June 2008, tried to arrest what amounted to a public relations disaster for an organisation which publishes more than 100 standards every month[151]. Collaborators of the ODF standard now—to pick up on a metaphor quoted earlier—have to worry about wolves in sheep's clothing working side-by-side at the specification drafting table. Microsoft itself has invested enormous resources in the complex process of authoring, distributing, marketing and implementing a vast specification which is unlikely ever to see large scale uptake by any products other than its own in the foreseeable future. And customers—governments, companies and individuals alike, the supposed beneficiaries of the entire process—also need to contend with what is at least a vexing choice between two largely overlapping ISO document format standards. Moreover new technological avenues continue to emerge: the growth of online collaboration tools such as blogs, wikis, Google Docs and Zoho Office are making, in some market segments at least, the office software suite increasingly redundant—a point emphasised by the Co-Chair of the OASIS ODF Technical Committee, Rob Weir[152]. In the rolling dialectical movements of late capitalism—towards both standardisation and differentiation, growth and recession, boom and bust cycles, all massively accelerated in and by the technological domain—no end but ever increasing displacements and relocations of the game take place. By early 2009, this could already be witnessed by the new directions taken by once-strident and vocal bloggers—either silenced completely, or focussed on new causes—, the rapid diminution of traffic on the ODF mailing list, and the substantially lower coverage on technology news sites[153].

As convenor of the BRM, Alex Brown, expressed it, with perhaps a hint of regret:

> 2008 has been an exciting year for document format standards. 2009 will, I predict, be rather more boring[154].

[150] McGibbon (2008b).

[151] ISO (2008c).

[152] Weir (2009).

[153] The number of messages on the ODF mailing list in the first half of 2008 was 772; in the second half the number dropped to 107 (OpenDocument Fellowship, 2008). Similarly Google Trends showed a large decline in searches and news articles for both "ODF" and "OOXML" after March 2008 (Google, 2009)

[154] Brown (2008b).

Signs of the "boring", maturing process of document format standardisation can be seen in a host of technical tests and discussions around technical points of concordance and divergence between ODF and OOXML. Nevertheless the seismic cultural shifts underpinning the two standards remain close to the surface, at least for those tasked with planning document management policy and infrastructure.

The following sections summarise the findings in relation to the dimensions of commensurability teased out in the narrative, and provide suggestions on how these might influence planning and decision making around document policies in some common scenarios.

Findings—Social Dimensions of Commensurability

Strategies

In the course of the controversy, both sides had been accused of various moves in pursuit of their desired outcomes. The moves can be distilled into distinct strategies—the means by which in which the players attempt to manipulate the outcome towards their own greatest pay-off, within the environment and according to the rules of the game. These are summarised here. The veracity of the claims are not assessed—it is sufficient that they have been made publicly, and therefore represent the strategies employed at the very least from the standpoint of the other players.

Microsoft is reported to have:

- Manipulated ISO national body meetings;
- Manipulated indirect channels, such as Wikipedia, online forums and blog commentary;
- Instigated a campaign involving both traditional forms of documentation—press releases, trade shows and developer documentation—and an active blogging strategy;
- Financially endorsed several consultancy and press reports which showed OOXML in a positive light;
- Supplied unnecessarily vast amounts of often dense technical information, requiring responses within short time-frames;
- Orchestrated under-hand arrangements with OpenDocument Format proponents, such as Novell;
- Employed similar and obfuscating terms, designed to confuse non-specialists;
- Purchased sponsored links in search engines related to OpenDocument Format terms;

- Pushed the OOXML specification through an industry consortium with little non-corporate involvement;
- Provided ambiguous legal assurances, as yet untested in court;
- Inflated the *technical* differences between the two formats;
- Deflated the *social* cost of maintaining two standards.

Meanwhile the ODF camp is reported to have:

- Developed blogs, websites and papers criticising OOXML (while not always discussing ODF);
- Lobbied ISO national bodies and other government organisations against OOXML;
- Ceded control of the ODF standard to two large corporate organisations (Sun and IBM);
- Manipulated the standardisation process as a means of furthering corporate objectives;
- Edited Wikipedia entries on OOXML in a biased way;
- Appealed to Microsoft conspiracy theories and stereotypes (at the extreme fringe of the debate);
- Ignored the need to support the *de facto* standard represented by *Microsoft Office* documents;
- Attempt to suppress and isolate other open source groups seeking to support OOXML;
- Promoted unjustified legal scaremongering;
- Disrupted the BRM by holding a rival event at the same time and location;
- Deflated the *technical* differences between the two formats;
- Inflated the *social* cost of maintaining two standards.

Figure 8.3 depicts broadly the lines of influence by which various players attempt to influence the outcome. Blue indicates *Pro-ODF*; red indicates *Pro-OOXML*; purple indicates *Neutral—Both*; yellow indicates *Neutral—Neither* and green indicates mixed positions—that is, strategies changed over the course of the controversy. Bubble size shows approximate significance of the player in the context of the game.

Analysis

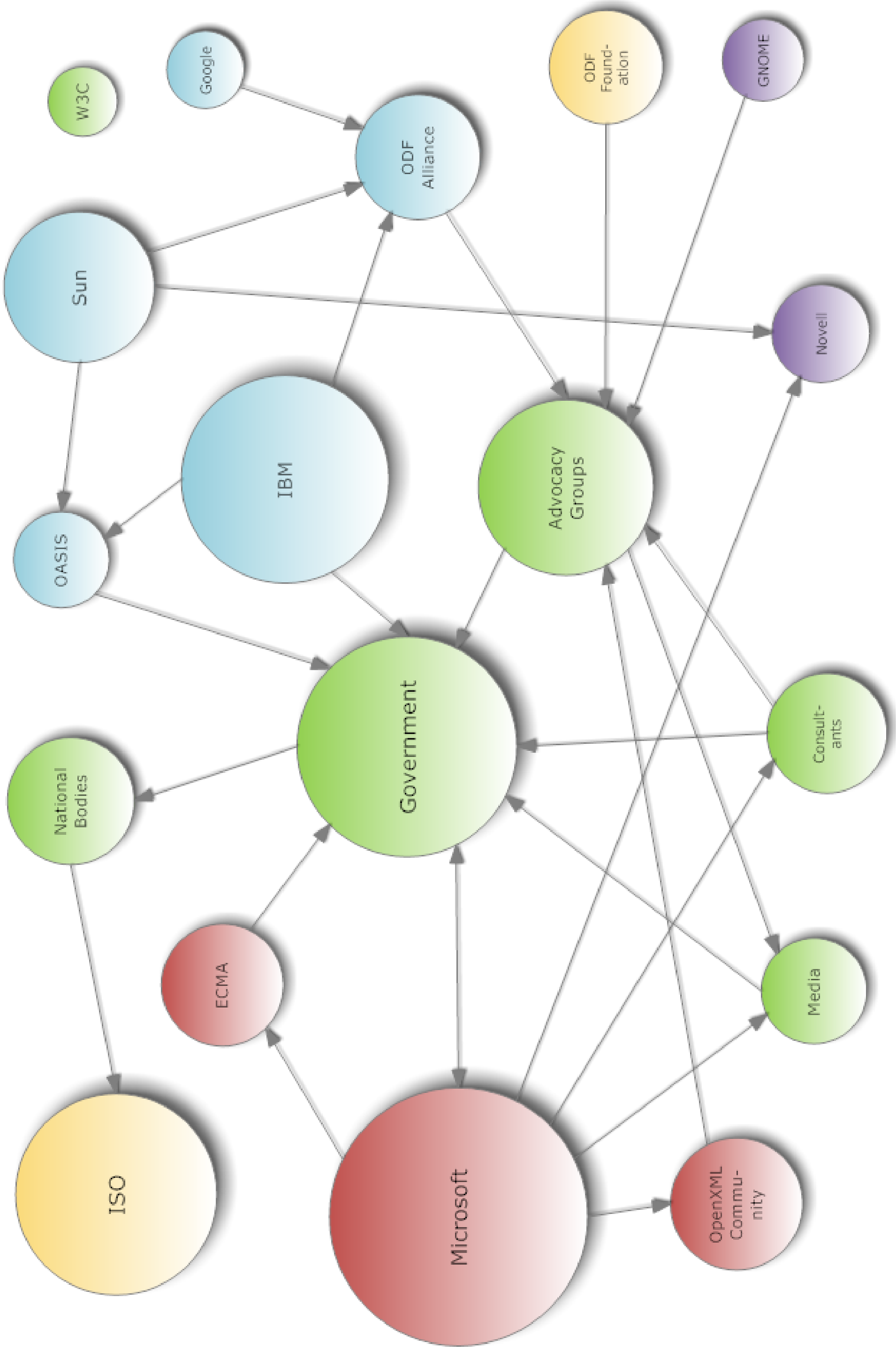


Figure 8.3: Players in the Game

The analysis of the social facets of the controversy highlight several dimensions of *in*commensurability. Identification of players and their respective pay-offs demonstrates that many pursue contradictory interests. At the most obvious level, the different business models of Microsoft and its corporate competitors—software licensing revenue versus advertising, hardware and service revenue—mean that in the area of document formats these companies find themselves diametrically opposed. Despite not competing directly in this market, Microsoft competes with each of these companies in other markets. Consequently the ability to unhinge one of Microsoft's key profit centres is of immense strategic value in the broader corporate struggle. Sun, IBM and Google have nothing to lose from the promulgation of open source office software, since they derive negligible sales in the market in any case. Microsoft, on the contrary, derives enormous revenue and profits from sales of *Microsoft Office*. Thus a clear difference can be identified in the degree to which the format in question is *linked to software sales revenue*[155]. Of course Sun, IBM and Google's position more clearly align—despite Microsoft's recent efforts—with open source and open standards advocates. The positive publicity provided by such advocacy is of considerable strategic value in the marketplace, all the more since Microsoft is frequently vilified in the same media circles. A second dimension is therefore the degree to which the format is *aligned with the open source software (OSS) movement*. This establishes a further effect of encouraging greater *distribution of design input* in standards development—despite some complaints in this area, the ODF specification has a broader base of participants than OOXML. Public forums such as the ODF mailing list, coupled with the distinctly uncontroversial progress of ODF through the ISO process, suggests a greater degree of transparency and *public involvement* in the format development process. This also suggests a *range of types of interests* motivating the development, rather than purely economic interests (which themselves might be multiple and overlapping).

On the other hand, the centralised design of OOXML is arguably warranted by one of its key design goals—supporting *backward compatibility* with the large corpus of existing *Microsoft Office* documents. Backed by the market dominant vendor of office document software, OOXML is also poised to be the *de facto standard*. In the world of *de jure standards*, however, ODF is the incumbent, having been unequivocally voted an ISO standard in 2006. This suggests that OOXML is *pragmatically* oriented towards the existing corpus of documents; ODF is by comparison an *idealisation* of the document format (subject to future uptake). On the question of commensurability (referred to within the debate as "harmonisation"), ODF proponents have advocated *unification* of the formats, while arguing at the same time it is contradictory to maintain two largely overlapping standards. OOXML proponents have argued exactly the opposite way—for *technical* in*commensurability*, and *social commensurability*.

The scope and scale of the debate has attracted immense publicity—ironically, this

[155]Here, and further below, use of suggested dimensional distinctions are italicised.

has benefitted *both* formats and their respective parties. In this—and perhaps only in this—instance, the consequences have been a win-win for at least the corporate players on all sides. However, the standardisation of OOXML has done much to raise the profile of ODF, while much of the publicity directed towards the Ecma group and Microsoft has been distinctly negative. Despite Microsoft's arduous efforts, apparent abuses of the ISO process have raised both ethical and legal concerns over the company's conduct. Warranted or otherwise, this stigmatisation extends even to its assurances not to press claims over particular specifications under intellectual copyright.

Meanwhile the level of *documentation* and industry *support* are important considerations for organisations looking to draft policy, procure software and services, and plan projects. Again, the controversy has clarified notable areas of obscurity in *both* formats. As noted earlier, the documentation around OOXML has been voluminous; its emergence has also highlighted missing parts of ODF, currently being addressed in new drafts of the standard. Equally the publicity around the debate has encouraged other software companies to announce support for one or both of the formats.

These factors are listed below, with the same ratings as used in the technical analysis above. Like the technical factors, the factors here are not necessarily independent or strictly mutually disjunctive.

	ODF	*OOXML*
Format linked to software revenue?	Low	High
Aligned with OSS movement?	High	Low
Distributed design?	High	Low
Transparent, with public involvement?	Medium	Low
Backwards-compatible?	Low	High
Represents range of interests?	High	Low
Incumbent *de facto* standard?	High	Medium
Incumbent *de jure* standard?	High	Medium
Pragmatic (versus idealistic)?	Medium	High
Rated *technically* commensurable?	High	Low
Rated *socially* commensurable?	Low	High
Positive publicity?	High	Medium
Ethical perception?	Medium	Low
Legal perception?	High	Medium
Documentation?	Medium	High
Industry support?	High	High

8.3 Conclusions: Assessing Commensurability

This analysis has demonstrated that employment of a framework which considers both technological and sociological dimensions is useful for considering commensurability of ontologies—or in the terms employed in this chapter, the harmonisation of document formats. It is by no means exhaustive—new amendments to either standard, or in the broader market, could easily force a correction to the conclusions arrived at here. From the limited and selective technological analysis, it was evident that across eight criteria—self-containment, abstraction, prescriptiveness, verbosity, referentiality, multiple methods, and classification—substantial differences were to be found in the two formats. After a sociological analysis of the recent controversy surrounding the standardisation of OOXML, a further sixteen factors were found which highlighted the different positions of the formats and its proponents. These reinforce the technical factors, and to some extent help explain them—when, for example, a market incumbent attempts to promote a second rival standard to consolidate its position while reacting to a number of economic, political and legal pressures, it might logically endeavour to ensure that harmonisation is difficult, that its specifications are rich, prescriptive, complex, highly abstract, and support earlier forms of its formats while providing a path for further change and innovation. Conversely, ODF, which witnessed greater community involvement while attempting to disrupt the market incumbent's dominant position, focussed on a simpler, more flexible document model, made use of existing standards and is more homogeneous with related document standards like HTML and DocBook. As a consequence though, it has suffered from perceptions of under-specification (in the case of formulas particularly), accessibility issues, and lack of compatibility with the overwhelming majority of office documents—those produced by *Microsoft Office* itself. Irrespective of differences, the publication of formats through the standardisation process appears on the whole to be of major benefit to consumers, both in increasing choice and promoting document interoperability—one of the major purposes of standardisation (Moore, 1998).

What use can be made of these findings? Here are three simple scenarios:

1. **Policy formulation**. A mid-size organisation reviews its document management policies, with a view to enhancing interoperability with partner, customer, supplier and government agency organisations. It finds that other organisations use both ODF and OOXML formats; reckoning on its limited resources and considerable technical *in*commensurability between the two formats, it decides upon a policy to support *both* at a policy level, while recommending continued use of *Microsoft Office* due to the *de facto* market leading position of the vendor, and its own in-house expertise and training. It also has several accessibility requirements which seem adequately fulfilled by the OOXML format, and a large body of documents it is in no rush to convert to a less pervasive standard. It uses a redacted form of the commensurability model in its evaluation.

2. **Software provisioning**. A government department seeking to renew its existing office productivity licenses issues a tender for provision of software and associated support services. Although it has a large corpus of existing docu-

ments, it is prepared to undertake a one-time format translation, subject to cost and feasibility. It plans to develop in-house software for mining document data, so the technical aspects of the format are significant. Other important decision-making factors include the simplicity of the format, the degree of non-commercial participation in its development, and its use of existing public standards. After applying the commensurability framework, it elects to standardise on ODF, and chooses a vendor to supply the software and provide associated technical support services. Although the translation proves to be costly, absolute formatting fidelity is not required—the key content is preserved, and the department also feels it can have greater input into the format's future direction through participation in the OASIS Technical Committee. Despite the efforts of OOXML to achieve standardisation, the apparent manipulations of the process by its principal sponsor make the department wary about the level of involvement it could expect.

3. **Software development**. A small software development company is building an open source content management system, and wishes to support existing standardised formats. It is essentially agnostic about which formats it supports—it has no particular vendor allegiances. However, it is particularly interested in extracting metadata from documents. After applying the commensurability model, it sees that support for ODF is easier, and moreover its "open source" ethos more closely aligned with the company's own position. On the other hand, it is aware of the large corpus of existing *Microsoft Office* documents among its potential customers. After looking at the overlapping areas, it decides to firstly support the DublinCore standard, since this is both simple, and (with minor differences) supported by both formats. Thereafter it plans to implement the ODF metadata, followed by OOXML metadata. The company recognises the dissonances between the formats, and develops its own "interoperability" schema to support both sets of metadata. Based upon the commensurability analysis, it can develop a suitably scoped project plan, and deliver support for standards in a suitable time-frame.

These scenarios all highlight the role of context in assessing commensurability—there is always at least a tripartite relation in its determination. There are the two ontologies, or in this case document formats, and the third party seeking to make use of them. A proper exploration of context is out of the scope of this discussion, but as these scenarios make clear, different contexts necessarily apply different dimensional criteria, different weightings to those criteria, and different degrees of methodological rigour in the evaluation of the criteria. The case study presented here could be, against different requirements, either too exacting or too cursory; nevertheless it demonstrates, in addressing both technical and sociological dimensions of commensurability, one manner in which the framework might be applied.

At the outset of this study I suggested that, although not dealing with Semantic Web ontologies directly, this analysis was justifiable on the grounds that it followed a debate with immense publicity, far more than typically attends the austere world of standards development. Outside of these pragmatic grounds, it provides a very concrete case study of just how non-technical, extrinsic factors can work to determine the technical specifications themselves. The manner in which the game has played out—part indeed of a much larger and ongoing contestation between rival companies, between the corporate and public sectors, between advocates of open source and intellectual property protection, between, even, nation states and geopolitical regions—demonstrates an aspect of structural determination inherent in market competition. This case study provides a fragmentary insight, then, into the modern dialectical relationship between standardisation and differentiation characteristic of the contradictory impulses of late capitalism. The evangelical tone of many of the participants on either side of the debate are far from accidental—it harkens back to the sociological diagnostics of modernity developed by Durkheim and Weber a century ago, which sought to underline the strong religious elements that pervade secular markets and societies (Durkheim, 2001; Weber, 2001). The language of game theory, introduced here to unfold the complex character of the debate, is useful for getting a grip on the tensions which reverberate within competing world views; but its premise of ends-driven rationalising agents ought not occlude the role of macro-economic and political structures in generating pay-offs for *both* standardisation and differentiation—as commentators on both sides noted. The technical and sociological dimensions of commensurability teased out here stand as parts to a whole—the world in which both demands and limits to commensurability arise. No model or framework will be entirely adequate to that world, but does serve an explicating function for the practical tasks of framing policy, scoping projects and measuring effort. In the case of documents—small but prolific slices of the world used to record human happenings—such tasks are inevitable, and heuristic methods of evaluation therefore highly desirable.

The next chapter moves on from case studies to a more direct examination of the framework itself. The examination consists of a pilot test, where the framework is operationalised in software form, and given to a small sample group of researchers to evaluate. The chapter presents a discussion of the software and the evaluation, in order to see what happens when other users try to make sense of the framework.

Chapter 9

Framework in Practice

> The process of "closure" ultimately adapts a product to a socially recognized demand and thereby fixes its definition. Closure produces a "black box," an artifact that is no longer called into question but is taken for granted. Before closure is achieved, it is obvious that social interests are at stake in the design process. But once the black box is closed, its social origins are quickly forgotten (Feenberg, 2002, p. 11).

The preceding case studies have demonstrated different applications of the commensurability framework developed back in Chapters 4 and 5[1]. The formal knowledge case study reviewed different approaches to knowledge representation in the emergence of information systems in the latter decades of the twentieth century; the upper-level ontology case study examined recent efforts to improve on the kinds of foundational existential categories discussed since Aristotle; while the document formats case study took a close look at the both the technical detail and sociological background of two rival document standards. Each of these cases demonstrates the application of the commensurability framework across different fields, working with different sources, with various refinements and adjustments along the way. In each case, though, there is a strong chance of confirmation bias, since the author of the framework is also the subject responsible for validating the framework. An open question towards the end of the study, then, is whether the framework can be operationalised and made useful for other researchers and analysts faced with comparable scenarios. This chapter explores that question through an evaluation of the framework itself.

The approach adopted here uses a software system to externalise and operationalise the framework—to place it in a form which others could apply to schema or ontology matching scenarios. In keeping with the aims of the previous case studies, this study is also exploratory. Several different software systems were developed and used in different ways to see whether the framework could be made intelligible, and practically useful, to others. This chapter documents the development and evaluation

[1] Sections of this chapter were published in the proceedings of the Ontology Matching workshop of the International Semantic Web Conference, 2006 (Magee, 2006), and in the January 2010 issue of the peer-reviewed Electronic Journal of Knowledge Management (Magee, 2010).

of these systems. The results of two systems are then presented, followed by some concluding remarks.

9.1 SOMET—Shared Ontology Matching EnvironmenT

Early in the process of trying to operationalise the framework in software form, a system called "SOMET" (Shared Ontology Matching EnvironmenT) was developed. The main purpose of the system was to facilitate collaborative ontology matching; in an early design of the current method, this kind of collaboration was to have made evident some of the difficulties of alignment and to locate areas of incommensurability.

The system allowed users to create semantic web ontologies and associated constructs—classes, properties, restrictions and individuals—in an online environment. In this respect it is similar to common desktop ontology design applications, like Protégé (Gennari et al., 2003) and SWOOP (Kalyanpur et al., 2006). It was also designed to permit limited matching of classes, through a drag-and-drop interface. Beyond this, users could also annotate ontologies, using OWL 1.0 annotation conventions, with a pre-defined set of properties loaded into the system. These properties were termed "semantic axes", and were intended to correlate to the different dimensions of the framework presented in Chapter 5. In turn, values ascribed to these annotations could be used in evaluating the commensurability of two ontologies, using a simple set of graphs plotting the values.

This system was presented at a poster session at the International Semantic Web Conference held in Athens, Georgia, 2006, and was further trialled by Common Ground Publishing, one of the industry organisations involved in the ARC project of which this study formed a part. The presentation was published in the proceedings of the conference, while the company used the tool to migrate a large existing XML schema of publishing terms into an OWL ontology format, using some scripts developed expressly for that purpose.

A formal pilot was planned, the purpose of which was to see whether the tool would assist users looking to compare and contrast two ontologies in a matching scenario. The pilot was not undertaken due to several reasons:

- The framework on which the system was substantially under-developed. As the case studies were developed, it became clear that a simple set of variables or dimensions was necessary but insufficient. In particular, the role of methodology came to occupy a more central position in the framework. The SOMET system provided a formal means for assigning valuations to variables, but no instructions or guidelines for how these valuations might be derived.
- In the course of conducting the case studies, the framework was generalised to a number of formal structures (relational databases and XML schemas, in

particular). Ontologies became the paradigmatic rather than sole case to which the framework could be applied.

- Finally it became clear that the effort required to build and maintain a system for actually constructing new ontologies was counter-productive, given the ultimate aim was to build a system to implement a framework for comparing existing knowledge systems. Far more time went into fixing bugs and adding features—tasks which were clearly ancillary to this aim. Given other systems (like the Protégé and SWOOP systems mentioned above) already did a far superior job with regard to these features, I thought it preferable to focus on another system, this time designed just around the framework itself—with the idea that Protégé or other ontology development tools could be used as part of an overall commensurability assessment.

9.2 Schema Profiling Toolkit

9.2.1 Background

In place of SOMET, in 2008 I began work on another system, the Schema Profiling Toolkit—the term "schema" being preferred to "ontology" or "system", as it would have greater resonance with some users of the software unfamiliar with the Semantic Web. The purpose of this system was to focus exclusively on the framework apparatus described in Chapter 5. By this stage, the framework apparatus had been applied, and also refined, through the subsequent case studies. What became particularly apparent during that process was the need both to accommodate an explicit declaration and treatment of the issue of methodology—how particular valuations of ontologies were arrived at, and how they could be justified—and also to allow considerable flexibility around the particular methodology used. In the working through of the case studies, it became clear that different sources—the ontologies themselves, historical documents, contemporary online discussions, auxiliary data such as financial filings and legal records, and so on—as well as different ways of engaging with those sources—quantitative or qualitative, "hard" metric counts or "soft" interpretive work—could yield valuable clues about the commensurability of ontologies. It also became apparent that the toolkit needed to provide as much support as possible for the framework, in terms of user interface design, hints, labels and documentation. Users of the toolkit needed to acquaint themselves with three areas: the technologies of ontologies and schemas; the methods of social science investigation; and the vocabulary and aims of the framework itself. While the first two of these might be presupposed in varying degrees, no-one would be *a priori* familiar with the framework, and so one of the key challenges became the design of the software interface, in order that the framework could be applied as naturalistically as possible, given the backgrounds of hypothetical users. In practice, this challenge would only partially be met.

Since the requirements of the toolkit could at best loosely framed in an exploratory sense, it needed to be built in an iterative fashion—first building a general scaffolding around the concepts put forward in Chapter 5, then filling in gaps, gradually re-working process workflows and form design, and adding documentation and so on as the toolkit grew. During an intensive construction process, in late 2008 and early 2009, I presented the toolkit to several pilot testers, who provided informal feedback around what areas were clear, and what areas remained obscure or difficult to use. Early in 2009, I became aware that refinement of the user interface was a potentially endless task—often feedback from even the handful of early users was contradictory, and within the scope of the exercise for which the software was developed, it would be difficult for the toolkit to be "all things to all people". Moreover the project was suffering from a familiar IT problem of "scope creep", as more and more features and documentation needed to be added to capture the complexities of the evolving framework, and to document these features for an uninitiated user group. This proved counter-productive in several respects. One of the motivations behind the framework was to reduce the time required to assess the scope of an ontology alignment task. One of the corresponding goals for the software, therefore, was that it would instrumentalise this aim as a kind of "agile" method, which could be quickly applied at the start of a project. However, as the documentation developed, it proved very difficult to provide clear instructions on how, for example, to interpret the different assumptions voiced on a mailing list without writing, effectively, an abridged guide to content analysis. Similar problems existed in the development of the software itself. One of the features I added was the ability to "tag" sources, to associate sources with a particular viewpoint or dimension of an ontology. But moving further down this line, while making the tool more powerful, would eventually lead to the development of more complex data analysis features—again, well outside the scope of the current system and its aims.

A consequence of the recognition of these difficulties was to reduce both the scope of the toolkit, and of the claims made about its evaluation. Since the toolkit is an online application, initially I had intended to invite members of various mailing lists, including the *Semantic Web* mailing list, to participate in its evaluation. The purpose would have been to conduct a modestly-sized anonymous study of blended quantitative and qualitative responses of the toolkit, after an initial introduction and a specified period for completion of a particular ontology alignment exercise. A pilot, conducted through a local group of researchers recruited by "snow-balling", was to provide some initial feedback, after which refinements to the toolkit would have been made, and then a general invitation sent out. In practice, the pilot provided both a reasonable set of responses in itself (with various caveats, described further below), and also alerted me to some of the difficulties with involving a larger cohort (also described below). Consequently, I have treated the pilot as, instead, the main findings of this part of the study, and have used those findings in an exploratory rather than confirmatory sense. A broader investigation of the utility of the software, and the underlying framework, now comprises a subject for further work.

The remainder of the chapter describe the toolkit, the process and results of its evaluation, and a subsequent discussion.

9.2.2 Outline of the Toolkit

The toolkit is an effort to embed into a processable form the framework presented in Chapter 5—it aims to make it possible for others to apply the framework practically to some ontology alignment or matching scenario.

Uses and Aims of the Toolkit

The following excerpts, taken from the "Introduction" to the toolkit, summarise its aims and uses:

> *What is the Schema Profiling Toolkit?* The Schema Profiling Toolkit is a tool which helps people assess how well information schemas or ontologies fit together. It does this by providing support for profiling the underlying *perspectives* of schemas. The tool also provides a minimal methodology framework, for defining and answering a set of questions which construct the profile.
>
> The software is designed to be used in the context of a particular *project*—where there is some schema-related task to be performed, such as the integration of two data sources. In this context, the software can be useful in planning and scoping the amount of work involved in integrating the sources. It can also be used to check on the results of concept or data mapping activities—to ensure intangible or implicit features of the schemas are retained ...
>
> *Why has the Toolkit been developed?* Information schemas are usually developed to model information in a particular domain—for example, geological objects, business processes or social organisations. This works well when people just need to access information from a single schema—but they also often want to search, combine, move or consolidate data from more than one schema. Because different schemas—developed by different people in different places and times—will often have overlapping or related concepts, this introduces well-known problems of system integration. Usually working out which concepts are related between two schemas is a time-consuming and error-prone task. The results of this work is typically some form of *mapping* from one schema to another. To help engineers with this task, several approaches have been developed

to automate—or at least partially automate—mapping concepts between schemas.

This problem is difficult enough within organisations—but on a global network like the World Wide Web, it becomes immense. The Semantic Web is a major effort, developed by the World Wide Web Consortium, to provide standards for defining information schemas for the web. In this context, schemas are called "ontologies", and are developed in a formal language called OWL (Web Ontology Language). A specialised area of research, ontology matching or alignment, has been examining ways of developing automatic mappings between ontologies. These typically produces algorithms which exploit specific relationships between the concepts of ontologies.

Sometimes though information schemas cannot simply be related in a concept-for-concept-like fashion. Like any other human-made product, an information schema is produced in a particular social or cultural context. The schema represents the assumptions, motivations and beliefs—the perspective—of a particular culture. These are not necessarily explicit in the schema itself—and are not therefore discoverable by algorithms. Yet they can be very important in determining whether two schemas fit together—whether they are *commensurable*. In a global environment, such extrinsic social factors—political, economic, cultural and legal—frequently need to be taken into account. They have major impacts on the costs, time and feasibility of projects.

The Schema Profiling Toolkit presents an overall framework, a basic methodology and a default set of dimensions for describing the perspectives of schemas, as a complement to the kinds of schema or ontology matching algorithms discusses above. It is designed to be used before or during some data integration, merging, migration or reporting project, to support better estimates of the scope of the project—in cases where the *commensurability* of schemas is in question.

Main Elements of the Toolkit

In line with the framework presented in Chapter 5, the toolkit consists of the following main elements:

- *Project Description*: A means for describing a project in which two ontologies or schemas compared. The description can be in general prose, or broken up into separate fields for specifying the purpose, background context, stakeholders and other project variables.

- *Dimension Taxonomy*: A two-tiered taxonomy of dimensions for describing ontologies. The first, more general tier of dimensions are applied qualitatively, in the form of open-ended textual descriptions, while the second, more specific tier of dimensions are applied quantitatively—as a simple score out of 10. A default set of dimensions, similar to those outlined in Chapter 5, is installed for each new project (these are listed in appendix C.1).

However, users can add, modify, remove and weight first (grouping) and second (individual) tiered dimensions. Assigned weights are used in the generation of weighted average quantitative commensurability results, as part of the more general reporting mechanism. The algorithm for computing these results was presented in Chapter 5.

- *Schema Profiles*: A "profile" of a schema or ontology consists of some generic fields—the name, web reference or URL (if available) and a description—as well as a set of qualitative and quantitative values corresponding to the dimensions described above. These collective values ought to aim to capture the general cultural perspective of the schema, in the sense discussed in Chapter 5. Together, they form the basis for an assessment of the commensurability of two or more schemas.

  If the schema profile describes an ontology represented in RDF/OWL format, and which is available on a valid URL, the toolkit attempts to parse the ontology to provide a series of metrics to help with assigning values to dimensions. For example, one of the default dimensions is whether an ontology uses predominantly classes or properties. The toolkit tries to generate counts of the number of classes and properties, and their respective ratio automatically. However, it does not automatically *set* any dimension values—this requires the input of the user of the system, who needs to calibrate the values relative to other schemas being profiled.

- *Data Sources*: An area for adding data sources (documents, web pages, financial records, interview transcripts or other sources of evidence), which describe the background conditions under which an ontology is developed and used. Individual sources can be added, modified, removed and tagged—associated with a particular schema or relevant theme. The sources are used to build the schema profiles.

- *Commensurability Report*: A reporting mechanism for assessing the commensurability of two schemas, based on the completed profiles. The report included results of both the qualitative assessment of dimension groups and the quantitative assessment of individual dimension values, based on the weighted average algorithm presented in Chapter 5. That algorithm is extended in two respects in the software implementation, which are outlined below.

- *Feedback Mechanism*: An evaluation form for users to evaluate the framework, the software and associated documentation.

The process of defining these elements was not clear cut. Initial drafts of the framework itself were revised substantially in the course of developing the previous case studies, and in the construction of the toolkit itself, as it became clear that a number of tacit assumptions needed to be teased out for the framework to be intuitive to researchers and practitioners in different fields. The "micro-iterations" of the toolkit also fed into the "macro-iterations" of the framework—and consequently, of the over-arching argument of the study—as a whole. Four specific adjustments were made to the framework weighted average algorithm presented in Chapter 5 for measuring commensurability:

- The software allowed only first tier (grouping) dimensions to capture qualitative judgments. While second tier (individual) dimensions could have notes accompanying quantitative assessments, the number and fine-grained nature of these dimensions suggested qualitative values would unnecessarily clutter the final reporting mechanism. Also, restricting qualitative judgments to just high-level categories such as "process" or "perspective" seemed more in keeping with the actual process I myself had undertaken in the case studies.

- The software introduced a separate dimension *type*, for dimensions describing the *relationship* between two schemas (the document formats case, where both schemas were developed with full knowledge, and largely in opposition to one another, demonstrated the need for this separate conceptual distinction). Since these dimensions do not apply to a *single*, but rather to a *pair* of schemas, it is the direct value instead of the difference between two values which is included in the algorithm for these dimensions.

- The software allowed dimension *group* as well as *individual* weights—it appeared more relevant to be able to adjust weightings at both a coarse and fine-grained level.

- Four different commensurability algorithm results were presented, with differing treatment of dimension weights: an unweighted average, an average weighted with just the grouping dimension weights, an average weighted with just the individual dimension weights, and an average incorporating both group and individual dimension weights. These allowed participants to review and, if necessary, calibrate the effects of the weights.

These refinements were integrated over several iterations of the software, in part to reflect the experience of the case studies, and in part to make the use and evaluation of the software more manageable from the point of view of users who had not been exposed to the framework before.

Toolkit Methodology

The methodology component of the framework was designed to guide an analyst in assigning values to the dimensions and developing an evaluation report on the commensurability of ontologies. It applies a redacted form of online discourse analysis (Schneider and Foot, 2004).

These elements were subsequently stitched into a workflow with a series of steps or tasks. The steps are not "lock-step", in that any step may be done in any order, and also performed reiteratively. However, their basic organisation suggests a relatively linear process. The steps, and associated descriptions, are to:

1. Configure the project—describe the project in terms of its purpose, constraints, resources and stakeholders;

2. Modify the dimensions—weight the default dimension set, and optionally, add and remove dimensions from the set;

3. Describe method and sources—locate background documentary or other kinds of evidence which can be used to develop profiles of the ontologies, and optionally, code the sources in terms of relevant user-defined categories. For example, a source may indicate that a particular ontology is a well-defined and well-supported standard, but excludes users from involvement in the development process;

4. Profile the schemas—evaluate the schemas in terms of the qualitative and quantitative dimensions constructed in step 2, and using the sources added in step 3;

5. Develop an analysis—analyse the commensurability of the profiles produced in step 4. The analysis may consider questions like potential scoping estimates for ontology alignment, specific problem areas and possible solutions;

6. Construct a commensurability report—brings together all of the preceding elements into a report, which can be used for further evaluation and dissemination.

Appendix C.2 shows a series of screen-shots of the software, depicting in particular the project definition, schema profiling and reporting screens.

Toolkit Guide

A set of web pages were developed to accompany the software. These pages include:

- An *Introduction* to the toolkit, which summarises its uses and aims;

- A *Plain Language Statement* outlining what the research project is about, who is involved, what is expected of users of the system, associated risks, benefits and rights, and what happens with the research results;

- *Instructions* on how to use the toolkit and complete the evaluation;
- A discussion of *methodology*—how to discover, interpret and analyse data sources within the context of the toolkit. In practice this discussion is a highly condensed introduction to online content analysis;
- An overview of the default taxonomy of *dimensions*, with a brief description of each of the first tier or grouping dimensions;
- A basic introduction to the *Semantic Web*.

The documentation was made available through links in the software, and parts of the documentation are also embedded inline, alongside specific features.

Technical Architecture

The toolkit was developed in the Ruby on Rails web application framework, using the Postgres relational database management system for data storage. To make use of available Semantic Web Java libraries for parsing and generating metrics for ontologies, the framework was deployed on JRuby 1.1.5, rather than on the conventional C-based Ruby interpreter. The OWLAPI Horridge et al. (2007) and Pellet 2.0 reasoner (Clark & Parsia, 2009) libraries were used for parsing and checking the consistency of ontologies.

9.2.3 Evaluating the Software

A pilot test of the software was conducted with a hand-selected participant sample, predominantly made up of researchers in the social science and computer science disciplines. It was conducted with 13 participants, recruited from RMIT University and several other research organisations. The participants were selected because they had some background with data integration, Semantic Web and ontology matching technologies, or alternatively, because they were familiar with the social science research methods presented in the toolkit.

In the pilot participants were invited to review a sample project comparing two commonly used tutorial ontologies, the *Pizza* (Rector et al., 2004) and *Wine* (Noy and McGuinness, 2001) ontologies. The project presented a scenario in which these ontologies need to be merged into a knowledge base of a new restaurant point-of-sale system. A very basic form of discourse analysis had been conducted into the background literature describing the cultural perspectives of these ontologies, and a quantitative evaluation against the default dimension set was also supplied. Finally a finished commensurability report was presented.

Participants were asked to browse both the interim steps and the completed report, and then to complete an evaluation survey. The survey consisted of a series of closed Likert scale and open-ended questions, designed to elicit feedback on the utility, ease of use and relevance of the following elements:

Table 9.1: Software Attitudinal Scales

Area	**No. of items**
The default dimension set	4 items
The methodology	4 items
The commensurability analysis	4 items
The software system	4 items
Overall	5 items

- Dimension model—the default dimensions used to measure the schemas;
- Methodology—the process of profiling the schemas;
- Reporting mechanism—the final analysis of commensurability;
- Software system—the implementation of the framework;
- Overall framework—how well the parts integrate into the whole.

Quantitative Results

The participants were asked to respond to a total of 24 Likert items. Three of these related to degrees of familiarity with, respectively, data integration, Semantic Web and ontology matching technologies—collectively these items form the scale of familiarity with relevant technologies. The remaining 21 items related to the following attitudinal scales:

All of the items were rated from "Strongly Disagree" to "Strongly Agree", and coded 1 to 5 accordingly. As the summary statistics in Appendix C.2 show, responses to items were generally favourable, with median values of 4 ("Agree") for 81% and mode values of 4 for 71% of the attitudinal scales. χ-square tests were also conducted on each of the items, with 90% of items significant at the $p > 0.05$ level and 57% significant at the $p > 0.01$ level. These results suggest the toolkit rated well, and would be useful for helping users translate and integrate schemas and ontologies in practical environments, and for assessing commensurability generally.

Qualitative Results

In addition, participants were asked open-ended questions about how the model, methodology, report and analysis, software and overall toolkit could be improved. They were also invited to add further comments. Nine out of the thirteen participants offered some kind of written feedback. Although this feedback was varied, the results suggested a more complex and critical picture than did the quantitative responses. A common criticism focussed on the lack of explanation of how and why the system could be applied in practice, especially in relation to the model and default dimensions. In the words of one participant:

> The model and its supporting documentation seem extremely easy to use and clear if someone already understands the "why" of doing this sort of comparison. If the tool were intended for professionals doing data integration projects on the ground (rather than people involved directly in more formal discussions of ontologies), it would probably need more upfront discussion of how the tool can be used in more everyday professional practice.

The same participant suggested a "walk-through" case study might help orient users through the use of the model and methodology in an applied setting. These comments were echoed in various forms by six other participants. A related complaint, voiced by several participants, was the difficulty and lack of clarity around the application of the model to the example scenario:

> Participant A: How to make things simple would be of great importance to the use of the model

> Participant B: I was confused as to what the model actually does also; how the values/weights are used.

> Participant G: The default model captures a vast array of possible dimensions on which to compare ontologies but perhaps only a few are actually important for any particular project.

Two participants also suggested simplifying or reorganising the dimensions:

> Participant D: Some of the heads for qualitative commentary could be consolidated—there are perhaps too many, and more scope could be given to users to create their own heads.

> Participant F: One improvement might be to break up the default model into several 'brackets' that might be more or less suited to different kinds of mapping challenges

Participants also found the methodology instructions too broad:

> Participant C: A specific case that ties into the specific example provided, would help "lay" users visualise how they might arrive at the point where they would develop a specific methodology and fill out other components of the tool, so that it would be easier to recognise what I think is a very practical, useful and intuitive environment for foreseeing potential complexities in a project.

> Participant F: The process of gathering background information to the mapping work is a little hazy . . . it might be possible to be far more directive and specific about the work that needs to done to prior to commencing the weighting against the default model.

> Participant G: The methodology is too broad and lacks focus.

Finally, three participants also suggested a reduction in, or reorganisation of, the number of dimension groups would be helpful. One participant objected to the general approach of the toolkit on more theoretical grounds. Expanding on this feedback in offline discussion, the participant viewed the problem of commensurability as one requiring agreement between ontological commitments at a higher level of abstraction. Echoing some of the more explicit comments on commensurability in Chapters 7 and 8, their view was that frameworks such as this could only help with "after the fact" reconciliation of schemas; what was required was *a priori* agreement before schemas and ontologies are designed and built.

In spite of these reservations, general feedback about the overall toolkit and framework were positive:

> Participant C: The underlying conceptual framework and toolkit seem like they would be quite useful in professional practice

> Participant D: Nevertheless, scaffolds like this are very helpful

> Participant F: Your default model grounds the work of mapping in concrete ways and this I think is a great invention.

> Participant H: Conceptually fascinating—and I can see how the questions posed in the process of designing a project could act as a point of dialogue between different components of a project team

9.2.4 Discussion

Although the quantitative results generally confirmed the utility of the toolkit, the qualitative feedback indicated the need for providing a clearer explanation of the purpose of the system, and specifically of how it could be applied in practice. Only one of the respondents indicated any specific improvements to the model, methodology, report or software design, indicating that amendments to the system can to a large extent be handled by improving the documentation—both in the associated guide, and through various hints and inline help. Overall, both forms of feedback indicated that the toolkit would be useful in improving understanding and accuracy of schema matching projects, although the results were less conclusive whether it would help lower time and cost components.

Some of the qualitative criticisms can be addressed through more specific documentation and user interface improvements. Others suggest that both the dimension model and methodology need to be tailored to practical scenarios. This could be achieved by developing "templated" models and associated activities for specific use cases, perhaps on a vertical industry basis or by identification of particular business "patterns" for ontology comparison and alignment. After these criticisms have been addressed, it is expected that further evaluations of the framework will be conducted via a series of case studies on organisations involved in real-world ontology matching.

There were several limitations of the study, which are consist with its treatment as an exploratory pilot. The participants were non-randomly selected, using a “snowball” technique where existing participants recommended other possible candidates. The sample size was small, and participants were encouraged, due both to time constraints and the “beta” status of the toolkit, to review an existing sample project, rather than to create their own. This meant the toolkit was reviewed against a decidedly artificial, rather than “real-world”, scenario.

While a more extended research survey had been planned, with a larger and random sample, the revisions to the system required for this were deemed out of scope. As it stands, or even with small cosmetic changes, evaluations of the system would likely elicit similar responses. The time commitment required to develop a comprehensive project description, set of salient dimensions, schema profiles and subsequent evaluation proved quite substantial—certainly more than hoped for at the outset of the project. Even through a local research network, participants had to be actively encouraged to complete the evaluation. Finding participants at a further remove willing to engage in this kind of evaluation would therefore be difficult. Indeed, what started as a kind of prompted survey turned into an exercise more closely related to a formal software testing process, even within the scope of the pilot project. The process also required considerably greater engagement from the participant group than had been anticipated.

In place of an extended survey, it is possible that various other approaches would be more useful. A workshop scenario, in which participants are provided a verbal overview of the research and demonstration of the toolkit, would provide a clearer introduction, and allow for the possibility of interactive feedback, questions and answers. Unfortunately I ran out of time to conduct an exercise of this sort, although this may be a option for further work in the future.

A further epistemological limitation with the application of the toolkit is that it tends to represent the perspectives underpinning schemas and ontologies as “point-in-time” phenomena. In practice, as the document format case study made clear, both perspectives and the conditions in which they arise shift frequently. Within a project context, in which estimates and planning activities are forecast, such point-in-time analysis is often still useful. But to capture this shift in the present toolkit would require an ability to move from static, point-in-time to dynamic, longitudinal profiles, which would capture the evolving qualities of schemas—and relationships between those schemas—over time. Given the number of dimensions introduced here, capturing this information would pose a problem of complex information capture, analysis and visualisation.

9.3 Pilot Study Summary

The two software approaches explored here—an ontology editing environment and the schema profiling toolkit—both represent various ways the framework can applied by other users. The first approach failed sufficiently to capture the complexity of the framework; the second approach proved to be useful in at least demonstrating the framework could be operationalised in software form—a process which in turn clarified some of the assumptions and constructs of the framework itself. However, in turn it failed to capture potential dynamic, longitudinal aspect of ontology commensurability. For an external analyst considering ontology alignment for a particular purpose, a static point-in-time assessment is nevertheless useful, arguably much more so when some of the other criticisms and limitations have been addressed. Similarly, the pilot made evident some of the difficulties of rendering a complex framework in software form; feedback indicated both further work on the usability of the system itself, and other methods of presenting it to users, would be helpful in overcoming these difficulties.

Importantly though, the software pilot has demonstrated that the framework can be successfully understood and applied by others—and so provides some confirmatory evidence of its utility beyond the case studies presented here. The next and final chapter considers the combined evidence of these studies against the initial aims and questions, and the subsequent elaboration of the framework, in summarising and concluding the work as a whole.

Chapter 10

Conclusion

> Concepts that have proven useful in ordering things easily achieve such authority over us that we forget their earthly origins and accept them as unalterable givens. Thus they come to be stamped as "necessities of thought," "a priori givens," etc. The path of scientific progress is often made impassable for a long time by such errors. Therefore it is by no means an idle game if we become practiced in analyzing long-held commonplace concepts and showing the circumstances on which their justification and usefulness depend, and how they have grown up, individually, out of the givens of experience. Thus their excessive authority will be broken. They will be removed if they cannot be properly legitimated, corrected if their correlation with given things be far too superfluous, or replaced if a new system can be established that we prefer for whatever reason (Howard, 2005, p. 35, quoting Albert Einstein, 'Obituary for Ernst Mach', 1916).

The concluding chapter reviews the argumentative arc the study has plotted: from its early framing of a question, through its detour in the literature review, the methodology and the theoretical approach, to its eventual elaboration of an answer, in the form of a framework and its application in a series of case studies. It then summarises the findings of the study, discusses some of its limitations, suggests areas of further work, and ends with several tentative implications which can be drawn from the findings.

One of the key conceptual tensions prominent throughout the study is that between semantic *standardisation*—where common arrangements of concepts and terms are used to describe a particular field or domain—and *differentiation*—where new emergent arrangements, tacitly or otherwise, oppose those already in play. It is this dialectical social exchange which, as much as anything else, could be said to provoke the question of commensurability between knowledge systems. At one extreme, a completely standardised ontology would indicate that, however fortuitously arrived at, its underlying conceptual scheme could be universalised beyond the point of further argument and conflict. At the other, a solipsistic conception of a system would suggest that its conceptualisation is irretrievably private, with only the semblance of semantic exchange taking place. Neither conception seems adequate to everyday experience, nor to the specialised social transactions which formalise our concepts into computer-manipulable information artefacts. Rather, meaningful semantic acts are performed within a broad marketplace, one which includes all manner of dialogue, ideas, conceptions, assertions, interdictions and questions. Semantic Web ontologies, however much they adhere to methodological and mathematical rigour, nevertheless only occupy more refined, exclusive real estate within this general communicative commerce, compared to the "messy retail business", as Brandom puts it, of everyday vernacular information exchanges. They remain tokens of exchange, symbols of value, expressions of epistemic capital alongside their natural language counterparts.

Retaining this analogy, one way of stating the guiding question of the study is whether it is possible to measure the degree to which the conceptual entailments inherent in knowledge systems are mutually *exchangeable*. Use of quantitative monetary metaphors can become strained, however, suggesting the schemes can be measured against some underlying common conceptual currency. That is in a sense to repeat the ambitions of a universalist semantics, displaced to a yet further conceptual scheme which acts as the measuring stick for the others. While an important part of the study resides upon just such a scheme, articulated as a framework and subsidiary set of dimensions, I have emphasised that the framework can only be considered *in situ*, in a practical, situational context. To shift metaphors, the framework adopted here is more by a way of a lightweight scaffolding rather than a finished construction, something to be erected, repositioned and refashioned pragmatically as the context for comparing conceptualisations demands.

Considerable academic research has sought to improve the performance and precision and recall rates of ontology matching algorithms. Dozens of publications each year exploit various properties of ontologies, seeking ways to automate the generation of conceptual matches between them. Automation is an important goal for large-scale ontology alignment; two ontologies containing 1,000 concept items each can produce a total of 1,000,000 candidate translations. Algorithms which limit these matches, even partially, clearly minimise the problem space for human agents. Utilising another of the central conceptual distinctions of the study, I have characterised algorithmic approaches as semantically *atomistic*—that is, meaning is implicitly reducible to atomistic concepts, rather than the holistic conceptual scheme to which those concepts belong. Translatability between ontologies or schemas is, under this conception, directly deducible from the number of individual concept matches.

This study has argued, on the other hand, for a more holistic conception of the degree of translatability between formal systems. Effectively, it has answered in the affirmative to the central research question: that such a conception can be useful in guiding any alignment exercise. Use of this conception in practice involves both "hard" technical comparison and some of the "soft" features more common to natural language translation, where context (both intra- and inter-textual), idiom, ambiguity and even the "aura of the text" have important roles to play. Attention to these features has practical advantages—it alerts the analyst to issues of scope, time, quality and accuracy which are otherwise invisible to purely algorithmic approaches. Equally, it directs attention to the situational context conditions in which the translation itself takes place. In some cases, purely algorithmic results may be sufficient; in others, human intervention is needed, precisely because the "texts" here—knowledge systems, such as ontologies or schemas—are insufficient in themselves to make evident the epistemic differences which underpin them. In short, some of the familiar questions of discourse interrogation—who has authored the text, how and why has it been developed, how has it been received and used, what sorts of implicit beliefs is the text committed to—are, in these cases, equally applicable to the problem of ontology alignment. In this study, such questions have been formalised into yet another schema, which forms a key component of the commensurability framework presented in Chapter 5, and is further applied in Chapters 6 through to 9.

The remainder of this chapter summarises the argumentative arc the study has plotted in response to the guiding research questions. It then outlines the findings and limitations of the research, along with suggestions for further work. The chapter concludes with a brief discussion of both the theoretical implications and practical import of the research.

10.1 Trajectory of the Study

The guiding research question for the study has been:

> Is the concept of "commensurability"—describing how electronic knowledge systems compare across a range of both sociological and technological dimensions—useful in guiding the alignment of these systems?

Several further subsidiary questions were also asked in the *Introduction*:

> What sort of *theoretical apparatus* can be used to describe the commensurability of ontologies?
>
> What kind of *general purpose framework* might be developed for evaluating the commensurability of ontologies?
>
> How can the *usefulness* of the framework be assessed?
>
> Can the framework be applied to *current cases* of knowledge system commensurability?
>
> Can the framework be implemented as a *software system*, and used by others?

The response to the main question is "yes"—the notion of commensurability, supported by a framework for assessing it, can be useful in alignment scenarios. The study has been structured around the argument for this response, and in the process has aimed to answer the subsidiary questions as well.

The first three chapters—the *Introduction*, *Literature Review* and *Methodology*—supplied the background for the main research question. The *Introduction* framed the question, providing an introduction to the Semantic Web and ontologies, outlining recent schema and ontology efforts, and raising the problem of commensurability. The central research questions of the study were then posed, and the structure of argument was summarised. Chapter 2—the *Literature Review*—provided a broad critical survey of literature from a range of disciplines which intersect around the idea of conceptual schemes. Work in fields as diverse as philosophy, computer science, anthropology, linguistics, social and cognitive sciences provide different but interrelated models. Some of these models were then further explored in Chapters 4 and 5. Chapter 3, meanwhile, outlined how the study mounts a theoretical framework for describing the commensurability of conceptual schemes, and how it uses various empirical studies to apply the framework. The question of how the usefulness of the framework can be assessed was also discussed here, along with trade-offs and limitations of the selected research methods. Together these introductory chapters provided the conceptual scaffolding for how the main and subsidiary research questions are responded to in the remainder of the argument.

In response to the first three subsidiary research questions above, Chapters 4 and 5 described the commensurability framework. Chapter 4, seeking to develop a theoretical foundation for the framework, explored the work of several recent thinkers in philosophy, sociology and cognitive science. It began with an analysis of the work of Kuhn, Foucault and Quine, who constitute important landmarks in what can very broadly be described as conceptual "structuralism". Through different analytic lenses, each of these authors presents meaning not as primarily a correspondence between verbal proposition and actual fact, but as instead reliant upon a coherent network of propositions, touching reality only at its edges. Several perspicuous critiques of these structuralist standpoints, voiced by Davidson and Derrida, were then put forward, followed by an interlude on a more contemporary debate of the so-called "science wars" by Hacking. Finally, a "rehabilitated" structuralist take on conceptual schemes was articulated through the more recent work of Habermas, Brandom and Gardenfors. Together these theoretical orientations help describe the different dimensions of conceptual schemes—as explicit representations in the form of technical products such as ontologies; as cognitive structures of mind; and as reflections of cultural and communicative practices. By drawing out these dimensions as qualitative and quantitative features which can be compared and contrasted, the basic theoretical ground-work was laid for the framework which then followed.

Chapter 5 then presented the framework itself, comprising a model of a commensurability scenario, a series of dimensions for evaluating ontologies and schemas, an outline of a methodological approach to conducting the evaluations, and a quantification of the notion of commensurability. This chapter presented the major claim of the study—that a general purpose framework can indeed be usefully deployed in practical ontology and matching scenarios, to realise better assessments of scope, time, cost and quality. The choice of default dimensions was justified here, in part with reference to the theoretical background discussed in Chapter 4. In particular, these dimensions were designed to describe those technical, cognitive, linguistic and social features most salient to the production and use of knowledge systems.

Chapters 6 to 9 demonstrated empirical evidence for this claim, and also aimed to answer the last two of the subsidiary research questions—whether the framework can be applied to actual cases of knowledge systems, and whether it can implemented in a software system and used by others. Chapters 6 to 8 presented a series of case studies. The first of these compared two prominent formal knowledge systems—relational databases and Semantic Web ontologies—providing in the process a schematic map of their development over the twentieth century. Key similarities and distinctions were analysed and discussed in the concluding sections of the study.

The second of the studies examined so-called "upper-level" ontologies. These are explicitly designed to cover abstract or foundational entities which, once specified, can be re-used by other ontologies. Not only would such conceptual re-use clarify what is meant by concepts such as *Space*, *Time*, *Process*, *Object* and other abstract concepts in those other ontologies, it would facilitate greater interoperability between them. The proliferation of upper-level ontologies in the past decade has led new questions of alignment and commensurability, in turn, to be asked of those upper-level ontologies themselves. This study reviewed five such ontologies which have been published, all within academic environments (though often involving some level of industry and government involvement too). Through an analysis both of the ontologies themselves, and available background publications and discussions, a series of distinctions were defined; against these distinctions the assumptions of these ontologies can be both made explicit, and further distinguished from one another. The subsequent analysis then developed several commensurability assessments of the ontologies against some hypothetical scenarios.

The third of the case studies covered a recent controversy over the standardisation of two document formats, OpenDocument Format (ODF) and Open Office XML (OOXML). This study sought to analyse both the technical specifications of the formats themselves, and the broader context in which they have been developed and used. The simplistic portrayal—that ODF is promoted by an "open source" community, while OOXML is motivated by corporate interests—was shown to dissolve into a more complex picture of shifting actor interests: individual consultants, advocates and spokespersons, competing standards bodies, internecine corporate rivalry and even some level of geopolitical governmental positioning. One result of this analysis was the recognition of the need for commensurability to be sensitised to the contextual conditions in which the alignment of knowledge systems takes place—different emphases across different dimensional criteria show markedly different levels of concordance or conflict.

Chapter 9 externalised the framework into a software system, which was then presented to other users to evaluate. A small pilot test was conducted across a dozen participants, and some initial feedback, both quantitative and qualitative, on the utility of the framework was collected and analysed. The feedback suggested considerable further work needed to be done for the system to provide greater direction to would-be users, making it easier to apply while simultaneously retaining the merits of the framework—its degree of abstraction and general purpose application. It also suggested that parts of the framework—particular dimensions and perhaps more directed methods and sources—could be distilled and simplified for use in specific situations.

10.2 Summary of Findings

The research has shown, most importantly, that a holistic orientation towards the problem of ontology alignment can be a useful supplement and corrective to what has been characterised as the atomistic approaches of ontology matching algorithms. The brief historical review of the differences between relational database and Semantic Web ontologies demonstrated that what at first sight appear to be mere syntactic technical differences can mask important ontological and epistemological distinctions. The survey of upper-level ontologies, where important aspects of philosophical and cultural orientation might be expected to be made more explicit in the ontologies themselves, showed that significant latent assumptions still could be found to motivate the selection and organisation of concepts. The analysis of the document format controversy laid bare a series of political, economic, legal and cultural factors coordinating the otherwise insular process of document standardisation. The innovation of the approach adopted here is not in the use of background assumptions *per se*; after all, most human expert translations between formal systems use background knowledge of this kind in an informal and heuristic way. Rather, the approach here is formalised and systematised in what I claim is a novel way. This makes the discovery of background assumptions relatively replicable, comparable and explicit, applicable to different domains, amenable to different kinds of systems and data sources, and scalable to more or less formal contexts. By seeking to describe knowledge representations against a range of dimensions—technical, linguistic, cognitive, social—the framework also portrays a semantic spectrum against which different granularities of meaning can be considered, from atomic symbolic concepts through to holistic cultural and social conceptual schemes. This helps an analyst involved in an alignment activity consider aspects of translation usually ignored by purely atomistic approaches.

At the same time, several qualifications have been issued in order to insulate treatment of the framework from criticism that it is a dogmatic answer to the question of commensurability. Firstly, commensurability is not posed here in metaphysical terms—it is not an inexorable feature of two ontologies (any more than it is for two languages). It is rather an analytic and evaluative determination made in a specific situational context. The framework is geared towards making and justifying such evaluations, relative always to the conditions and goals of that context. Hence, any quantitative or qualitative commensurability value derived through use of the framework ought not be abstracted out of this context—though, as with any estimation, it can be referenced alongside these contextual attributes. Secondly, the framework is intentionally open-ended in terms of which dimensions are used to profile ontologies; how these dimensions are rated; and what kinds of methods, sources and interpretive frames are used in the extraction of background assumptions about the ontologies. This gain in flexibility is at the expense of some further complexity and lack of epistemic validity—but seems adequate to the aims of the framework as a heuristic, guiding tool-kit aimed at practitioners. Thirdly, as some users of the software explained, the value of the framework may be more in the *process* of "making explicit" tacit assumptions, than the final evaluative result. In particular, being able to show evidence of particular decisions of translatability can be very useful in many project planning and scoping scenarios.

10.3 Limitations

One significant theoretical limitation relates to the epistemological claim about commensurability. Throughout the study I have argued commensurability is a relative, interpretative judgement bestowed upon systems of knowledge—an analytic rather than an ontological category. Unlike Kuhnian or Whorfian incommensurability, then, which posits lack of translatability as intrinsic to the paradigms or languages under consideration, the term here could be used in an adjectival sense—"commensurable for..." or "incommensurable with regard to...". Nonetheless, the structural motif which is written through the theorisation of conceptual schemes avoids the descent into semantic atomism, which does away with schematisation entirely. For, treated pragmatically rather than platonically, always with regard to the contextual conditions of an interpretive assessment, coarse grained commensurability of knowledge systems can usefully capture qualities of conceptual translation which fine-grained concept-by-concept matching cannot. However, the obvious implication is that commensurability conclusions are heavily relativised, by both situational context and the interpretive "bent" of the analyst. Practically, this makes assessments of commensurability less re-useable, weakening the appeal of the framework beyond the immediate scope of a translation requirement or project. One response to this line of critique is that the framework nevertheless makes for a more explicit, systematic and constructive appraisal than pure intuitive assessments might otherwise do. As the case studies demonstrate, together the model, dimensional criteria and methodological suggestions provide, then, a strong evidentiary basis for those interpretive conclusions.

A subsidiary concern relates to the method of composition of the framework. Chapters 2 and 4, in particular, spend considerable time reviewing existing literature on ontologies and related disciplinary areas, in order to compose a model and series of dimensions as part of the framework. The result is accordingly deliberately syncretic, combining a mix of suggestive inputs from philosophy, linguistics, cognitive and computer sciences, and various strains of sociological research. It might be argued that such a synthesis glosses over important disciplinary and perspectival areas of incommensurability itself—thereby undermining its own overt argumentative position. Such an approach could be deemed a strength as much as weakness; it can, moreover, be justified on purely pragmatic grounds—to ignore findings from some of these complementary areas of research is to miss important heuristic hints when developing assessments of commensurability. Consequently, the synthesis of different approaches, orientations and methods makes the resulting framework more generalisable, robust and reusable.

If the study then rests its case at least in part on practical grounds, it is equally important to acknowledge some important limitations in the empirical evidence presented. Firstly, the semantic web is itself a nascent information technology platform, in spite of increasing academic and industry attention. This has made selecting multiple ontologies in the same or related domains difficult. Only one of the three case studies examines ontologies, and this is clearly insufficient as a basis to extend to the general case. I have justified the other case studies on grounds that the commensurability of ontologies is an exemplary case of the more general problem of translatability and interoperability of knowledge systems—incorporating database and mark-up schemas and formats. As more ontologies are published and used, it ought to be easier to develop further studies of this sort, to refine the framework for systems and languages of different levels of expressivity.

Secondly, in spite of the avowed aim to develop an easily applicable, lightweight framework, the case studies themselves clearly take time, effort and some domain knowledge to design and undertake. For many practical projects, it is unlikely that studies of the sort conducted here will be feasible. There is clearly a trade-off between the sophistication and depth of the commensurability assessments, and the cost, time and resources required to generate them. Similar tensions can be found between the intention to construct a generalisable model which can be applied meaningfully to specific contexts. As it stands, the framework may suffer from being overly formalised and abstract; further work would be needed to examine whether the proposed dimensions and methods, in particular, could be "sliced and diced" to suit situational conditions without loss of coherence.

Thirdly—and related to the previous limitations — as the software pilot showed, it was difficult to communicate what exactly should be done with the framework. Despite the fact that the software attempted to operationalise the framework in a relatively linear form, participants in the pilot were unclear exactly what they were supposed to do with the myriad of options: to set up ontologies for comparison; to configure dimensions; to add data sources; to develop a matrix of dimensions; and finally, to view the resulting report. Clearly some of these difficulties related to extrinsic factors of the software user interface design, framework nomenclature, familiarity of the participants with ontologies, and the method used to execute the pilot—a gentler introduction to the aims of the software may have given users a better sense of what they were looking for. However, further work is certainly needed to ascertain the extent to which these difficulties related to intrinsic limitations of the framework itself. Unfortunately, the issue of lack of significant expertise in ontology design and modelling—an issue related to the relatively nascent state of the Semantic Web discussed above—makes finding suitable candidates for undertaking further testing difficult at this time. Anecdotally, where I have presented some of the content of the study around the framework and case studies in workshops and seminars, substantial time tends to be consumed in presenting "fundamentals" about the Semantic Web and ontologies themselves. It is therefore more likely to find suitable areas of application in more traditional areas of system and data integration.

10.4 Further work

Several indications of the need for further work are mentioned in the *Limitations* section above: in particular the need to apply the framework to "real-world" data integration scenarios, ideally involving other domains covered by available ontologies, and possibly using cut-down variations. In spite of the limitations above, the case study findings in particular do suggest the framework has successfully passed a preliminary "speculative" stage of theorisation and research application. To evaluate how the framework could move from this stage to one of industrial application requires, principally, further studies moving along different methodological lines to those adopted to date.

One approach would be a series of controlled workshop environments, conducted with students or practitioners working with databases, schemas and ontologies. In this context, the framework could be presented as an assisting guide to problems of data translation. Participants' engagement with the framework would ideally be monitored longitudinally, with periodic refinements being reincorporated back into the framework. Under this approach, participants' feedback would not only evaluate but positively revise the framework. A variety of more granular methods—interviews, surveys, structured and unstructured observation techniques—could be incorporated within an overarching workshop format. More perspicuous quantitative measures could also be drafted, to assess benefits obtained from applying the framework in terms of direct metrics like time, cost and resource usage in projects. Equally, consultation with participants could serve to improve the quantitative and qualitative reporting aspects of the framework, possibly in conjunction with revisions to the software system presented in Chapter 9. Moreover the framework would benefit from integration into existing software and data project management approaches and methodologies. Various forms of "agile" design and implementation approaches have gained popularity in the past decade; conceivably, the application of a framework like this throughout a project's life-cycle could improve the error-fraught aspects of project scoping and estimation—concerns typically fore-grounded in these approaches.

While the situational context in which commensurability is assessed has featured prominently, relatively little has been said about what *kinds* of context might exist, and the corresponding impact this might have on such assessments. Again, further empirical evidence, in the form of surveys and observation, might yield a useful taxonomy of alignment scenarios along these lines. Similar to the knowledge system dimensions, a series of variables could be formulated to model the context itself, which in turn could be used to refine further quantitative commensurability results. The following distinctions are indicative of the directions such work could potentially undertake:

- Whether the alignment is relatively *minimal*—(few concept need to be common) or *maximal* (most concepts must be common)
- Whether the alignment needs to be *precise* (with high confidence level thresholds) or can afford to be *vague* (low confidence levels are tolerable)
- What level of *effort* is permitted, *a priori*, or required, *a posteriori*, for the translation

Since situational dynamics vary considerably, a flexible—and extensible—taxonomy would be required in any event, much as has been suggested within the framework outlined here.

10.5 Conclusions

The introduction to this study referred to Foucault's pronouncement of the "great tables" designed in the seventeenth and eighteenth centuries. The legacy of this historical taxonomic impulse, for ordering things in classificatory hierarchies, grids and lattices, is the now-mundane promiscuity of organisational technologies in all facets of life. Human actors are engaged everywhere in electronic classificatory practices: as "knowledge workers" and collaborators, as consumers and purveyors of aesthetic and cultural taste, as socially engaged citizens and friends, and through a variety of other roles. The Semantic Web represents the most ambitious program yet for organising global information into a "web of data", where all knowledge would be reducible to interconnected factual assertions, represented as triples and conceptually coordinated through ontologies. Such a program is far from being realised yet, in part due to the incommensurability of the systems which would organise and house these assertions.

A clear implication of the analysis conducted here is that the hyperbole surrounding technological approaches to semantics needs to be tempered by suitable recognition of both the potentials and limits of communicative meaning within social and cultural spheres of human engagement. The holistic orientation advocated here, along with the derivative framework and case studies, aim at a more realistic assessment of whether and how knowledge systems can be integrated. This realism, arguably, will be manifested in pluralised, locally integrated and fragmentary "semantic webs"—at best, in partial accommodations of the visionary dream of interconnected and homogenised information services.

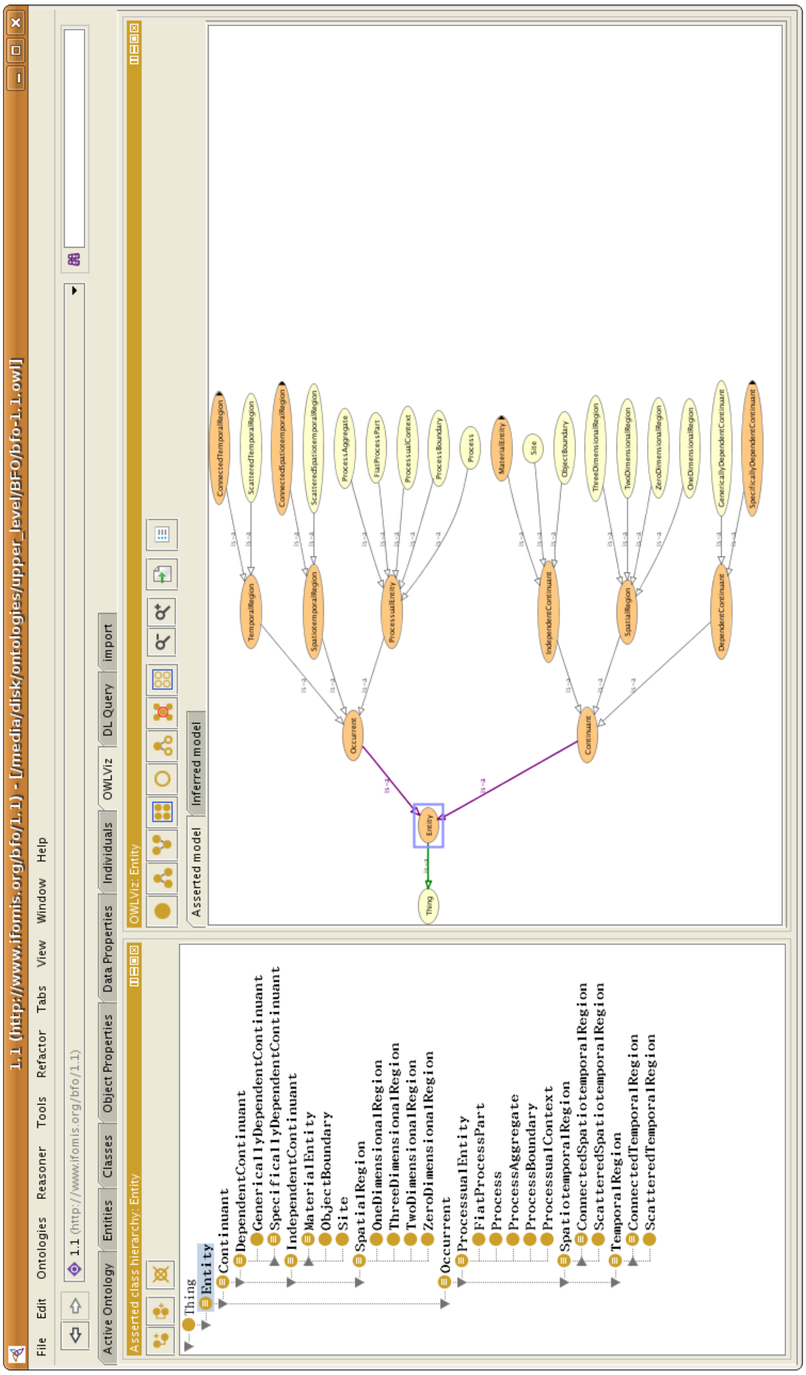
The study has suggested commensurability is a structural and irreducible feature of conceptual translation, independent—or at least isolatable—from judgements about either the utopic or dystopic potentials of the Semantic Web. The case for assessing commensurability has been put forward on pragmatic grounds; yet it is also worth acknowledging that the question of commensurability has an implied ethical dimension. Either end of the commensurability spectrum represents a certain kind of nightmarish scenario—either a totalising conformity to a singular conceptualisation, or entropy into a series of private and incommunicable understandings. Different modulating social forces, engaged in a dialectical interplay over cultural conceptual schemes and knowledge representations, thus act as an unintended ethical regulating device between these twin "steady states" of semantic conformity or solipsism. Endeavouring to assess commensurability between knowledge systems also implies a certain ethics of technology—adopting a "principle of charity", as Davidson puts it in a different context, in trying to understand the motives, interests and perspectives of the cultures responsible for them. As partial, in turn, as these understandings themselves are likely to be, they represent ethically as well as pragmatically justified acts oriented towards the coordination of meaning between knowledge systems.

Appendix A

Upper-level Ontologies—Supplementary Data

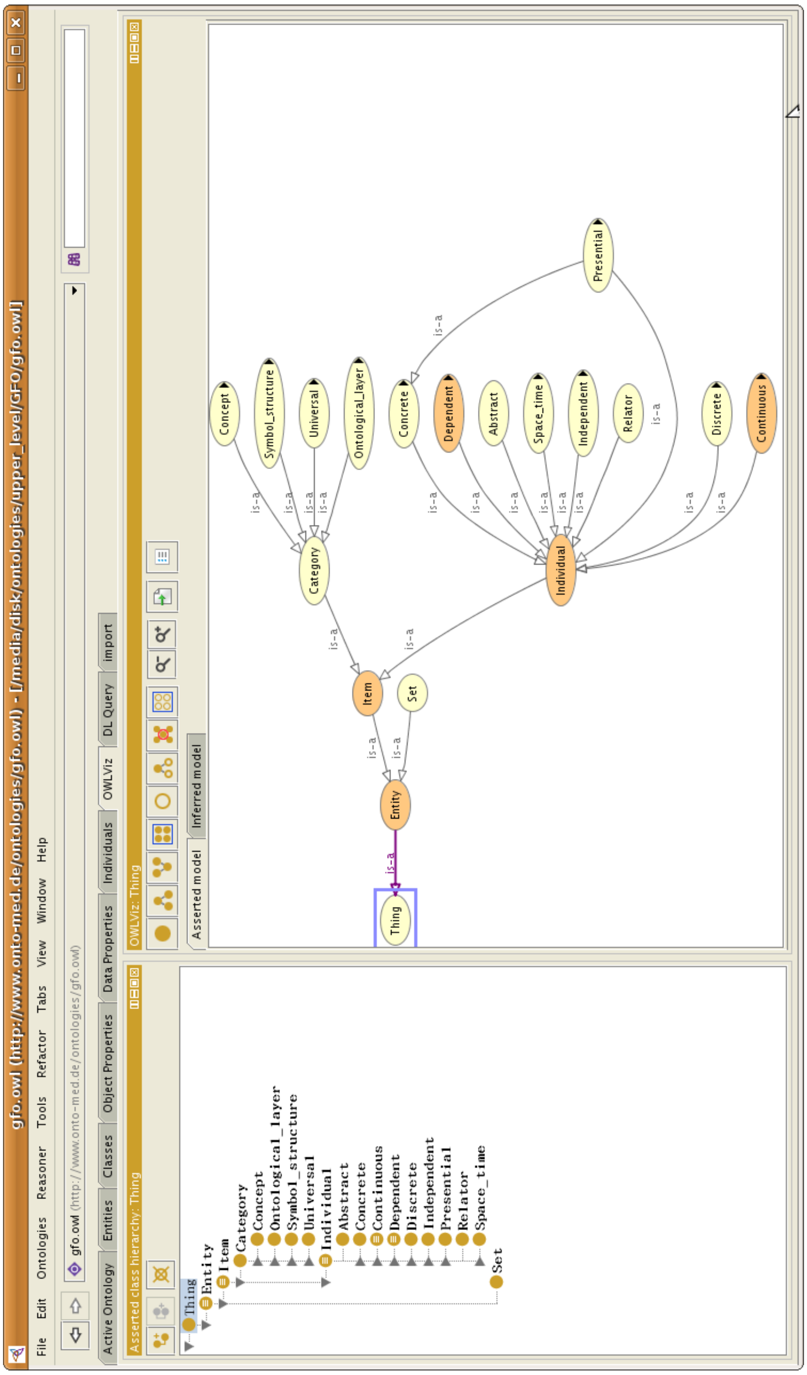
A.1 Upper-level Ontologies in Protégé

BFO

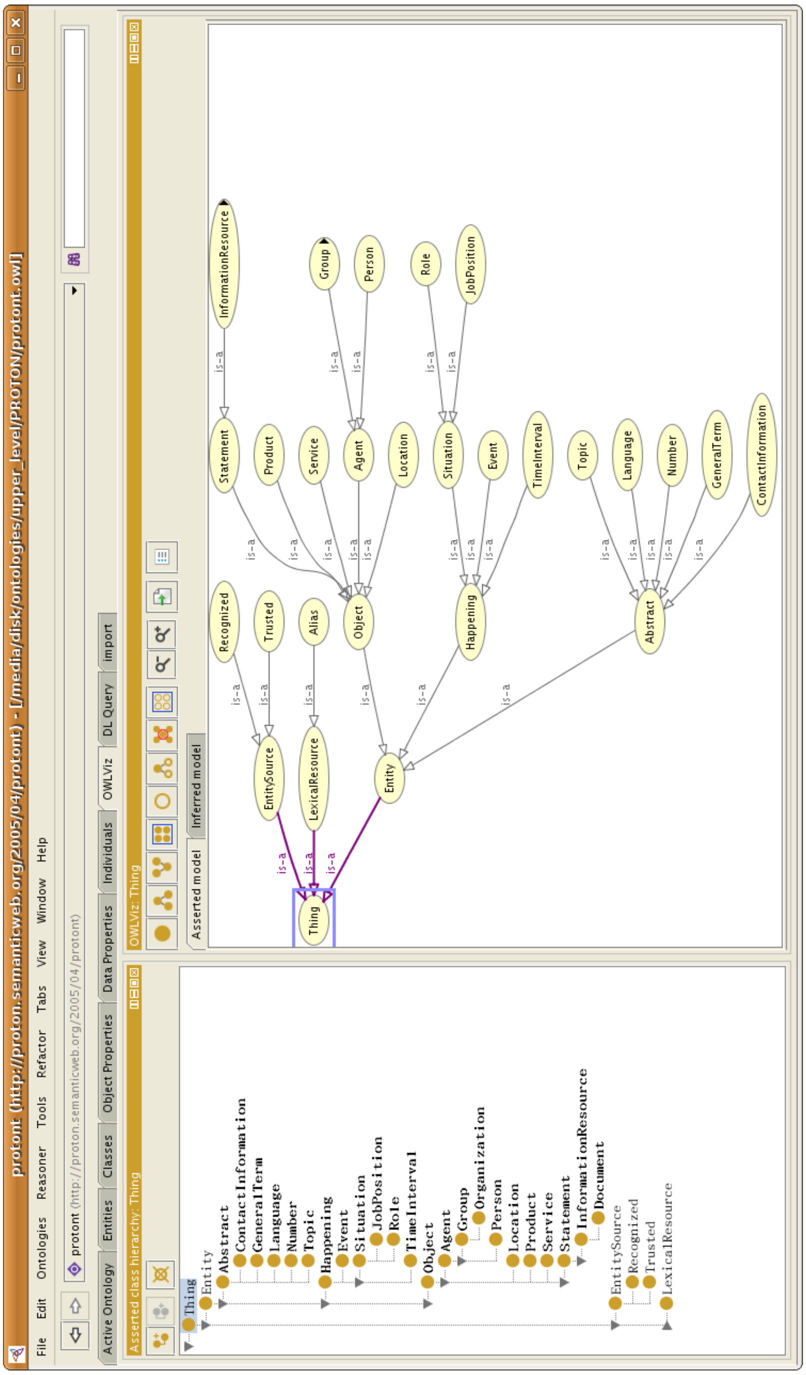


1.1 (http://www.ifomis.org/bfo/1.1) - [/media/disk/ontologies/upper_level/BFO/bfo-1.1.owl]
File Edit Ontologies Reasoner Tools Refactor Tabs View Window Help
1.1 (http://www.ifomis.org/bfo/1.1)
Active Ontology Entities Classes Object Properties Data Properties Individuals OWLViz DL Query import
Asserted class hierarchy: Entity
OWLViz: Entity
Asserted model
Inferred model
Thing
Entity
Continuant
DependentContinuant
GenericallyDependentContinuant
SpecificallyDependentContinuant
IndependentContinuant
MaterialEntity
ObjectBoundary
Site
SpatialRegion
OneDimensionalRegion
ThreeDimensionalRegion
TwoDimensionalRegion
ZeroDimensionalRegion
Occurrent
ProcessualEntity
FiatProcessPart
Process
ProcessAggregate
ProcessBoundary
ProcessualContext
SpatiotemporalRegion
ConnectedSpatiotemporalRegion
ScatteredSpatiotemporalRegion
TemporalRegion
ConnectedTemporalRegion
ScatteredTemporalRegion

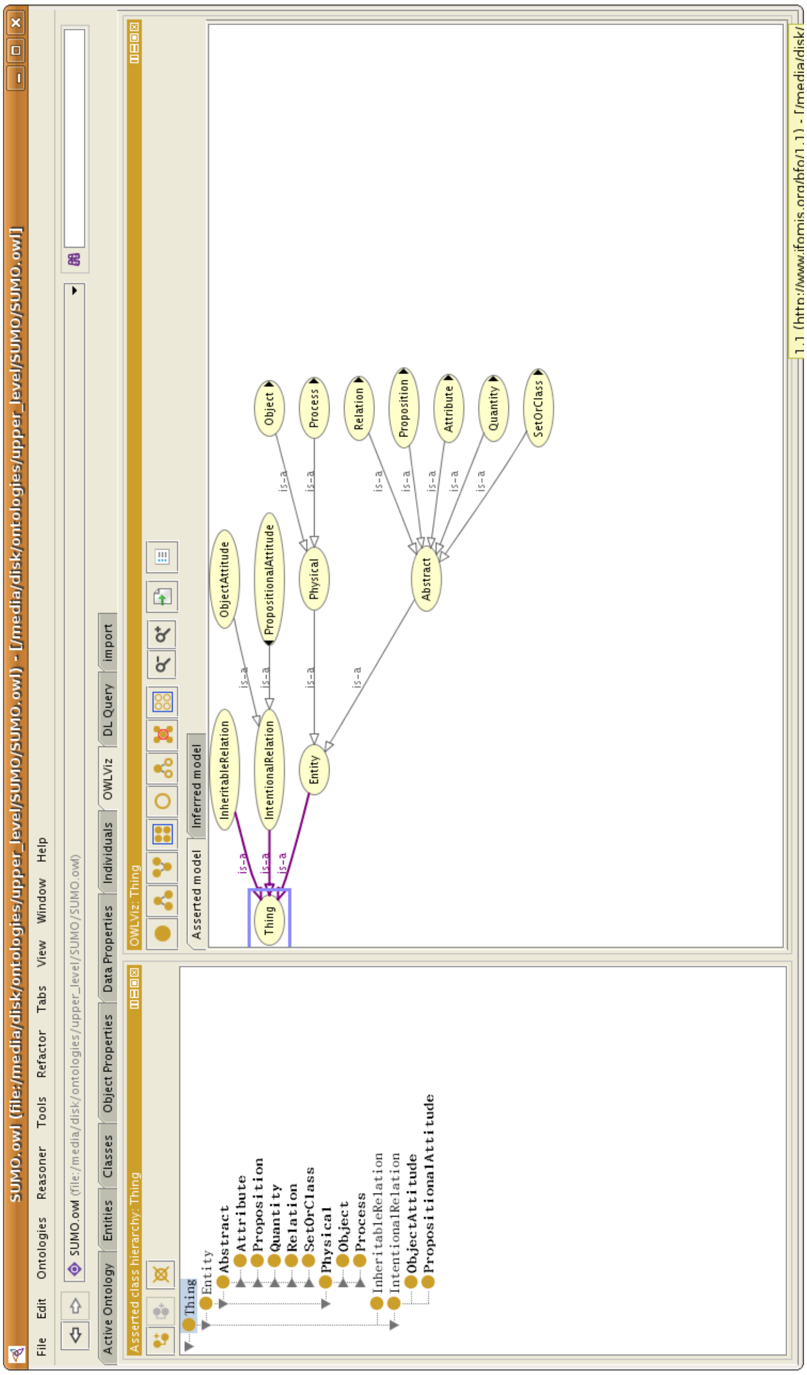
GFO


gfo.owl (http://www.onto-med.de/ontologies/gfo.owl) - [/media/disk/ontologies/upper_level/GFO/gfo.owl]
File Edit Ontologies Reasoner Tools Refactor Tabs View Window Help
gfo.owl (http://www.onto-med.de/ontologies/gfo.owl)
Active Ontology Entities Classes Object Properties Data Properties Individuals OWLViz DL Query import
Asserted class hierarchy: Thing
Thing
Entity
Item
Category
Concept
Ontological_layer
Symbol_structure
Universal
Individual
Abstract
Concrete
Continuous
Dependent
Discrete
Independent
Presential
Relator
Space_time
Set
OWLViz: Thing
Asserted model
Inferred model
is-a

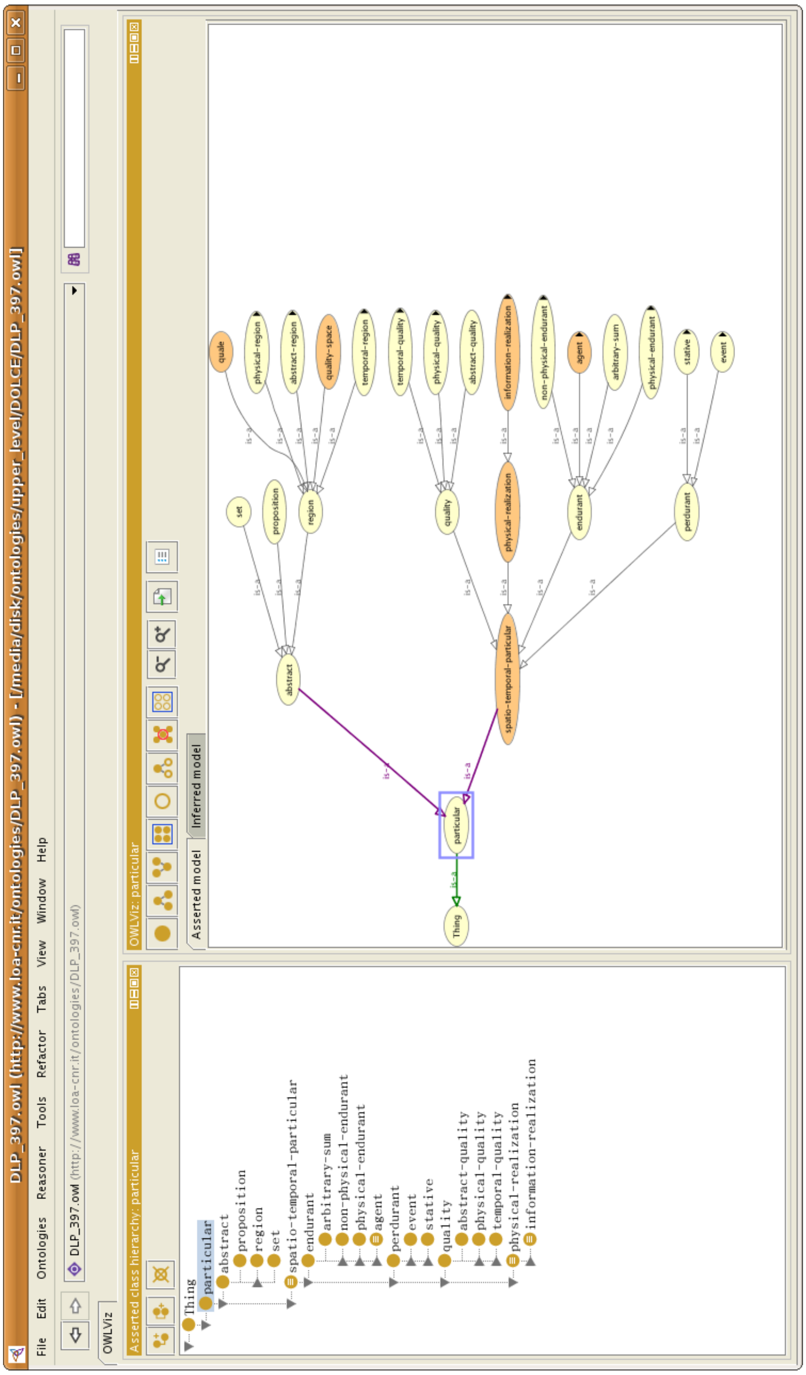
PROTON


protont (http://proton.semanticweb.org/2005/04/protont) - [/media/disk/ontologies/upper_level/PROTON/protont.owl]
Asserted class hierarchy: Thing
OWLViz: Thing
Asserted model
Inferred model
Thing
Entity
Abstract
ContactInformation
GeneralTerm
Language
Number
Topic
Happening
Event
Situation
JobPosition
Role
TimeInterval
Object
Agent
Group
Organization
Person
Location
Product
Service
Statement
InformationResource
Document
EntitySource
Recognized
Trusted
LexicalResource
Alias
is-a

SUMO


Thing
Entity
Abstract
Attribute
Proposition
Quantity
Relation
SetOrClass
Physical
Object
Process
InheritableRelation
IntentionalRelation
ObjectAttitude
PropositionalAttitude
is-a

DOLCE


DLP_397.owl (http://www.loa-cnr.it/ontologies/DLP_397.owl) - [/media/disk/ontologies/upper_level/DOLCE/DLP_397.owl]
File Edit Ontologies Reasoner Tools Refactor Tabs View Window Help
DLP_397.owl (http://www.loa-cnr.it/ontologies/DLP_397.owl)
OWLViz
Asserted class hierarchy: particular
Thing
particular
abstract
proposition
region
set
spatio-temporal-particular
endurant
arbitrary-sum
non-physical-endurant
physical-endurant
agent
perdurant
event
stative
quality
abstract-quality
physical-quality
temporal-quality
physical-realization
information-realization
OWLViz: particular
Asserted model
Inferred model
Thing
particular
abstract
spatio-temporal-particular
set
proposition
region
quality
physical-realization
endurant
perdurant
quale
physical-region
abstract-region
quality-space
temporal-region
temporal-quality
physical-quality
abstract-quality
information-realization
non-physical-endurant
agent
arbitrary-sum
physical-endurant
stative
event
is-a

A.2 Conceptual Distinctions between the Ontologies

Note: Forward slash characters (/) are used to indicate subsumption conceptual relations, square brackets ([]) indicate sibling classes, and pipe characters (|) indicate a sequence of two or more classes ($[A|B]$ means that A and B share the same parent class, and both are suitable candidates for the concept in question).

Table A.1: Conceptual Distinctions between the Ontologies

Conceptual Distinction*	**Ontology**	**Concept**
Spatial / Temporal		
	BFO	$/Entity/Continuent/SpatialRegion$ $/Entity/Occurrent/TemporalRegion$
	GFO	$/Entity/Item/Individual/Space_time/Space$ $/Entity/Item/Individual/Space_time/Time$
	PROTON	$/Entity/Object/Location$ $/Entity/Happening/TimeInterval$
	SUMO	$/Entity/Physical/Object/Region$ $/Entity/Abstract/Quantity/PhysicalQuantity/ConstantQuantity/TimeMeasure$
	DOLCE	$/particular/abstract/region/physical-region/space-region$ $/particular/abstract/region/temporal-region$
Collective / Individual		
	BFO	$/Entity/Continuant/IndependentContinuant/MaterialEntity/ObjectAggregate$ /Entity/Continuant/IndependentContinuant/MaterialEntity/[Object — FiatObjectAggregate]
	GFO	$/Entity/Set$ $/Entity/Item$
	PROTON	UNKNOWN
	SUMO	$/Entity/Abstract/SetOrClass$ $/Entity/Physical$

Table A.1: Conceptual Distinctions between the Ontologies

Conceptual Distinction*	**Ontology**	**Concept**
	DOLCE	*/particular/abstract/set* */particular/spatio − temporal − particular*
Abstract / Concrete		
	BFO	UNKNOWN
	GFO	*/Entity/Item/Individual/Abstract* */Entity/Item/Individual/Concrete*
	PROTON	*/Entity/Abstract* */Entity/[Object|Happening]*
	SUMO	*/Entity/Abstract* */Entity/Physical*
	DOLCE	*/particular/abstract* */particular/spatio − temporal − particular*
Continuant / Occurrent		
	BFO	/Entity/Continuant /Entity/Occurrent

Table A.1: Conceptual Distinctions between the Ontologies

Conceptual Distinction*	**Ontology**	**Concept**
	GFO	/Entity/Item/Individual/Continuous /Entity/Item/Individual/Discrete
	PROTON	/Entity/Object /Entity/Happening/Event
	SUMO	/Entity/Physical/Object /Entity/Physical/Process
	DOLCE	/particular/spatio-temporal-particular/endurant /particular/spatio-temporal-particular/perdurant
Independent / Dependent		
	BFO	/Entity/Continuant/IndependentContinuant /Entity/Continuant/DependentContinuant
	GFO	/Entity/Item/Individual/Independent /Entity/Item/Individual/Dependent
	PROTON	UNKNOWN

Table A.1: Conceptual Distinctions between the Ontologies

Conceptual Distinction*	**Ontology**	**Concept**
	SUMO	/Entity/Physical /Entity/Abstract/[Relation—Attribute—Quantity]
	DOLCE	/particular/spatio-temporal-particular/[physical-realization—endurant—perdurant] /particular/spatio-temporal-particular/quality
Conceptual / Physical		
	BFO	UNKNOWN
	GFO	/Entity/Item/Category/Concept /Entity/Item/Individual
	PROTON	/Entity/Abstact/[GeneralTerm—Topic] /Entity/[Happening—Object]
	SUMO	/Entity/Abstract/Proposition /Entity/Abstract/Physical
	DOLCE	/particular/abstract/proposition /particular/spatio-temporal-particular

A.3 Word Frequency Analysis Details

Table A.2: Word Frequency Analysis

Rank	**SemWeb**		**Ontolog**	
	Word	**Frequency**	**Word**	**Frequency**
1	rdf	35104	ontology	28507
2	web	35042	community	22013
3	semantic	25767	shared	17448
4	university	18017	leave	14464
5	data	15991	time	11591
6	owl	15902	ontologies	10759
7	information	13291	different	9311
8	ontology	11245	language	8907
9	papers	8798	web	8857
10	resource	8769	logic	8614
11	workshop	8692	knowledge	8448
12	uri	8571	semantic	8328
13	knowledge	7667	people	8054
14	research	7587	work	8008
15	systems	7230	information	8000
16	example	7120	way	7903
17	conference	7011	set	7894
18	people	6426	pat	7831
19	ontologies	6147	john	7705
20	xml	6138	point	7249
21	applications	6138	model	7235
22	usa	6095	subject	6972
23	class	5816	things	6898
24	new	5600	theory	6882
25	work	5593	family	6751
26	different	5548	world	6718
27	html	5545	say	6655
28	semantics	5093	make	6562
29	way	5058	example	6535
30	services	4782	need	6502
31	foaf	4765	data	6490
32	technology	4751	systems	6402
33	submission	4680	two	6309
34	uk	4625	context	5886

Table A.2: Word Frequency Analysis

Rank	**SemWeb**		**Ontolog**	
	Word	**Frequency**	**Word**	**Frequency**
35	type	4588	semantics	5784
36	list	4572	system	5711
37	rdfs	4545	being	5634
38	name	4500	first	5547
39	make	4493	know	5545
40	subject	4448	peter	5543
41	need	4401	color	5452
42	language	4394	terms	5439
43	paper	4361	new	5293
44	know	4341	formal	5242
45	technologies	4341	open	5222
46	want	4293	part	5115
47	time	4292	something	5073
48	international	4252	meaning	5053
49	uris	4244	common	5021
50	things	4224	owl	4863
51	two	4209	discussion	4646
52	first	4174	original	4639
53	content	4123	list	4637
54	thing	4080	concepts	4572
55	something	4035	problem	4506
56	application	4010	thing	4505
57	description	3980	agree	4497
58	open	3957	join	4474
59	world	3911	possible	4468
60	management	3875	class	4456
61	property	3873	call	4444
62	say	3841	bounces	4421
63	business	3830	sense	4371
64	model	3700	sent	4365
65	software	3686	real	4345
66	sparql	3605	each	4344
67	service	3596	session	4336
68	germany	3555	another	4334
69	case	3464	true	4278
70	document	3454	business	4191

Table A.2: Word Frequency Analysis

Rank	**SemWeb**		**Ontolog**	
	Word	**Frequency**	**Word**	**Frequency**
71	being	3446	standards	4175
72	system	3434	process	4147
73	problem	3417	useful	4124
74	point	3407	project	4117
75	tools	3406	number	4075
76	computer	3353	mean	4004
77	science	3285	want	3976
78	user	3217	level	3944
79	page	3213	fact	3904
80	set	3199	rdf	3871
81	context	3186	why	3818
82	submissions	3178	question	3793
83	query	3153	find	3778
84	original	3100	word	3634
85	following	3082	case	3633
86	reasoning	3080	since	3592
87	available	3071	human	3584
88	important	3050	person	3565
89	th	2960	type	3562
90	group	2954	without	3558
91	project	2953	regards	3529
92	person	2930	concept	3519
93	part	2918	rather	3517
94	really	2917	view	3504
95	question	2902	order	3501
96	each	2899	take	3499
97	languages	2897	still	3487
98	domain	2882	axioms	3479
99	find	2881	logical	3436
100	social	2820	standard	3425

A.4 Summary of *Ontolog Forum* discussion, April and June, 2007

Preliminaries

The thread begins in April 2007, with a forwarded request by Paola Di Maio for participation to a conference on "Ontologies for Emergency Management"[1]. After several further messages in April, under the title "Disaster Management ontology BOF in Delft", the thread is taken up again in early June.

Early on in the renewed conversation, the question of multiple ontologies in different contexts is raised by Sean Barker:

> That is, I don't think that "event" can be represented by a single ontology, and that it should be represented by a set of factor ontologies (for scale, cause and actor) for which there is some measure of agreement. Further, that what should be codified is the upper ontology, such that the ontology can be extended by subclassing for the local situation—for example, the upper ontology class "wild animal incident" might be subclassed in Africa to "Elephant rampage", but that is not a code we would use in the UK[2].

This initiates further discussion on the question of multiple ontologies. Bill Andersen offers the following advice:

> If you have some entity or entities E that can't be represented by a single ontology and which you will represent using "factor" ontologies, then one of these must be the case:
>
> 1) The factor ontologies are inconsistent when combined, in which case there's not much point in talking about E in the first place except in the sense the representation so made could be read by humans (for which we already have great natural languages).
>
> 2) The factor ontologies are not inconsistent when combine, in which case could you clear up what you meant by "I don't think that "event" can be represented by a single ontology", since clearly in this case they can be so used[3].

On the same day, John Sowa responds with an exploration of further possibilities:

> Those are two important points, but they don't exhaust all the options. There are many cases where the ontologies happen to have some features that create inconsistencies, but with some revisions those inconsistencies

[1] Di Maio (2007).
[2] Barker (2007)
[3] Andersen (2007).

> could be eliminated by redefining some of the terms. There are also many cases where the same thing is viewed at different levels of granularity or from different perspectives. Any inconsistencies caused by such methods could also be eliminated, in principle.
>
> However, the job of eliminating every one of the inconsistencies that could arise could take an enormous amount of effort. Instead of striving for a global consistency of everything, it might be better to adopt methods that don't require global consistency[4].

To which Waclaw Kusnierczyk replies with a request for clarification:

> The discussion would certainly be made clearer if one could support the claims with a simple example; e.g., two ontologies that taken together are inconsistent, which cannot be reduced to a single consistent ontology, and which both are necessary to cover the needs for all involved in modeling the domain. (01)
>
> As in mathematics, illustrative examples help in understanding dry theories. I sympathize with Bill, and would like to see a counterexample to what he says[5].

And Barry Smith—one of the BFO authors—replies with a link to a paper he has authored, which offers an example of "ontological pluralism"—a standpoint for supporting multiple incompatible ontologies (in both the philosophical and technical senses), which are nevertheless equally "contrained by realism" (Grenon and Smith, 2008).

Perspectives on the "Continuant—Occurrent" Distinction

At this stage the discussion is re-labelled as "Two ontologies that are inconsistent but both needed", and another 160 messages follow in June before the discussion peters out towards the end of June. The question of disaster management with which the thread began is left long behind in intriguing, lengthy debate which follows. I will pick out quotes which seem to exemplify the different positions which proponents adopt.

The first response, from Pat Hayes, seeks to dismantle the very idea of "ontological pluralism"—an idea which is also central to the epistemological take of BFO and DOLCE ontologies. In a long post, Hayes begins with a rejoinder to the effect pluralism can be done away with:

> These two 'irreconcilable' ontologies ARE reconcilable, if one does things right. The basic error is to assume that what a philosopher means by 'exists' has to be rendered into the logical existential quantifier[6].

[4]Sowa (2007a).
[5]Kusnierczyk (2007).
[6]Hayes (2007a).

He continues with the claim that the occurrent/continuant distintion is less ontological than terminological:

> ... the continuant/occurrent distinction is basically a distinction between *how we use names* when talking about spatiotemporal entities. It should not be seen as a fundamental ontological distinction: it is merely a linguistic distinction between modes of expression[7].

That is, the distinction between viewing things as existing either *in* time, in a three-dimensional space, or *through* time, in a four-dimensional spacetime, is semantically *useful* but not ontologically *necessary*:

> To the extent that they fit with ontological intuitions, and with linguistic usage, they are useful and important. But one can admit all that, and even include them as categories in a formal framework, without requiring that they constitute a rigid taxonomy, so that every physical thing MUST be in exactly one of the two categories and as a matter of logical necessity CANNOT be in both[8].

In passing, Hayes also makes reference to the BFO and DOLCE ontologies:

> I know that your framework and Dolce both use it, and are both used by real people in real settings. But that in itself is not evidence that a similar but simpler framework which does not have this distinction in it might not be even more use[9].

Smith, in reply, does not follow up on the substance of the debate, offering a terse pragmatic defence. Sowa, responding in turn, with a criticism of blind pragmatism: "I have serious concerns about taking informal terminologies and dressing them up with formal axioms"[10].

This message is followed by further series between Smith and Hayes. The benefit of the abstract distinction is argued for Smith on increasingly pragmatic grounds—at one stage he claims:

> [Pat Hayes] >Fine. But then the question arises as to whether your ontological >framework, which requires this distinction, is of more use than a >similar one which does not. (013)
>
> I think we need to test this empirically. So far we are winning—the GO is, by several measures,the world's most successful ontology[11].

[7]Hayes (2007a).
[8]Hayes (2007a).
[9]Hayes (2007a).
[10]Sowa (2007b).
[11]Smith (2007a).

This part of the thread ends in a kind of violent agreement about the potential translatability of continuants and occurrents:

> [Pat Hayes] >I don't think that [the translation between continuant/occurrent entities and spatiotemporal processes] will be much of a problem, most of the time. >Translating from c/o to spatiotemporal is really not much more than >judicious deletion. Translating in the other direction will require >some pattern-recognition to 'see' c- and o-type formulations, and >maybe in some cases splitting a concept into a continuant and its >lifetime (which are identified in spatiotemporal). >>I would say, in passing, that my views on this issue have been >informed in large part by trying to create useful interoperation >between a number of different ontologies.
>
> I agree with Pat. Indeed I could embrace the views expressed in these last two paragraphs verbatim[12].

A new correspondent, Don Conklin, summarises the state of the debate to date, in an exasperated tone:

> OK, this has been an interesting thread. I've come to agree with the notion that at some point, occurrents and continuants merge. Amen. I suppose at the sub atomic level, everything pretty much looks like an occurrent and at the level of the universe an awful lot of things look like continuants.
>
> Down here in the trenches, trying to explain such matters to the "normal" folks who are the users of the ontologies I build is not a productive use of time for me. I will count on Pat and company being able to manage the translation if and (hopefully) when needed[13].

Diversions

The discussion then precedes down a differnt path, and title, "Probabilistic Ontologies", in which Kathryn Laskey argues for the introduction of a "fuzzy" logic for representing degrees of certitude[14].

A separate track off the main line of argument, titled "Ontology-building vs Data Modelling", examines the distinction between "ontologies" and "data models"—a more familiar artefact of information engineering[15].

Both discussions are interesting in picking up issues raised in the previous case study. After a dozen or so posts each, the discussions run out of steam.

[12]Smith (2007b).
[13]Conklin (2007).
[14]Laskey (2007a).
[15]Barkmeyer (2007).

Metaphysical Dilemmas

The main thread resumes with a new debate, branching off the discussion of continuants and occurrents, about the role of metaphysics in ontology engineering. On June 16, Chris Partridge attempts to broaden the discussion:

> At one level we have a debate about what the continuant-occurrent distinction is. I would like to suggest that it may be useful to step back...
>
> It seems to me that these choices are metaphysical, in the sense that no amount of empirical data can decide the issue...
>
> It seems to me that one of the roles of the top ontology is to clarify what [metaphysical] choices have been made. Deciding on what choices to make (and on what basis to make the choices) is probably the first step in building the top ontology[16].

After some initial concern over the vague, allusory connotations of the term "metaphysics", Hayes suggests such general speculative philosophy is overly emphasised among ontology engineers:

> ... there is a dangerous tendency, which others in these lists have noted, for philosophical writings to be treated with a kind of uncritical awe by non-philosophers, so that they—the texts—are treated with a reverence that they do not deserve...
>
> One should never forget that most philosophers work not by doing anything empirical or even by talking to people who do anything empirical, but by reading and criticizing what other philosophers have written. The result can be rather in-bred, and indeed is often so remote from the actual world that it is hard to even make any sensible connection between the concerns of a good deal of philosophy (including metaphysics) and anything in the real world at all...
>
> On the whole, I suggest, it is probably better to re-do ones own metaphysics from scratch than to try to read through the history of philosophy and sort out the very small fraction that may be relevant[17].

Laskey replies that this "DIY" approach is implausible:

> It is not possible to re-do from scratch. One always starts with what one has absorbed from the surrounding culture. (Laskey, 2007b)

Hayes acknowledges the role of metaphysics in ontology development, but suggests science-derived intuition is a more useful grounding for foundational ontological axioms (Hayes, 2007d). Laskey agrees this can be useful starting point, with the caveat of "for all practical purposes" (Laskey, 2007c).

[16] Partridge (2007a).

[17] Hayes (2007c).

Partridge takes up the challenge to rebutt the argument about metaphysical redundancy, by parodying Hayes' words in relation to logic:

> For example, there is a dangerous tendency, which (unfortunately) others in these lists have not noted, for logical writings to be treated with a kind of uncritical awe by non-logicians, so that they—the texts—are treated with a reverence that they do not deserve. One should never forget that most logicians work not by doing anything empirical or even by talking to people who do anything empirical, but by reading and criticizing what other logicians have written. The result can be rather in-bred, and indeed is often so remote from the actual world that it is hard to even make any sensible connection between the concerns of a good deal of logic (including FOL) and anything in the real world at all. (05)
>
> On the whole, I suggest, it is probably better to re-do ones own logic from scratch than to try to read through the history of logic (not sure why one should need to read the history) and sort out the very small fraction that may be relevant[18].

The post is concluded with a recognition of the difficulty of engaging with "metaphysical" texts, but suggests intuition leads to more dangerous naivety:

> If this is a moan about the intellectual effort it takes to get useful stuff out of the philosophy texts—I can see your point. But your proposed solution seems to me to make the situation worse[19].

Sowa follows this with a quote and a comment:

> "Those who cannot remember the past are condemned to repeat it." (05)
>
> With respect to logic, the same ideas have been learned and forgotten repeatedly throughout the past 50 years of AI and computer science. Unfortunately, each reinvention has usually been worse than the one that was forgotten[20].

Hayes responds by suggesting that science and logic—unlike metaphysics—can be measured by *progess*:

> The difference now is that logic *has* become a field in which technical progress (mathematical rather than scientific, but progress for all that) has been made... There are no universally accepted results, no 'normal science', no theorems, in metaphysics or even philosophical ontology (a

[18]Partridge (2007b).
[19]Partridge (2007b).
[20]Sowa (2007c).

> different field from ours, but related). There are only rival opinions, arguments and points of view: some of them most persuasive and the result of very deep thinking, but opinions nevertheless[21].

Partridge notes some argumentative slippage here—from an "empirical" to "consensual" foundations. Philosophical inquiry cannot ground ontological engineering precisely because it is "pre-paradigmatic", according to Hayes:

> Where to start: So your criterion has moved from empirical (including science both hard and soft) to a discipline at a Kuhnian paradigm stage, where there is a community that accepts the 'normal' paradigm. This, of course, now excludes the soft sciences such as economics and sociology, which are pre-paradigm. But maybe you are happy about this. (Are you about to construct your own?) I would suggest a criterion of pragmatics, if it works, is more appropriate. Also, philosophy is often regarded as dealing with pre-paradigm, pre-empirical matters—when they become more tractable, they become science—as natural philosophy became natural science[22].

Hayes concurs:

> OK, then logic is now 'science', and philosophy still isn't. Which really was my only point[23].

Concluding Remarks

For all intensive purposes, conversation drifts into different terrain at this point. A new participant, Peter Brown, questions the value of the debate:

> Could someone sum up where this thread is going? Or is it just a philosophical stroll in the park (or Platonic cave, I'm not sure what...)? Frankly, apart from a partially illuminating Philosophy 101, has anything actually been said that advances the cause of ontological research and practice? If so, someone care to draw some conclusions?[24]

Both Partridge and Hayes offer some defence—but no conclusions. Partridge offers:

> Perhaps I can explain my motivation.
>
> My work in ontological engineering focuses on ontologies for largish business operational systems. In these, it is extremely useful to have a semantically consistent framework across large and varied data sets. I have

[21] Hayes (2007e).
[22] Partridge (2007c).
[23] Hayes (2007f).
[24] Brown (2007).

> found that for this it is useful/essential to have a good(ish) top ontology. I have found that much of what exists in this top ontology is formal and metaphysical—and that a rudimentary understanding of metaphysics is useful/essential in devising and (at the beginning) using the top ontology.
>
> Pat's original (I think, mischievous) comment about adopting a DIY approach seems to me a recipe for disaster for this kind of work—hence my response. I was attempting to point out what I saw as some inconsistencies in his rationalisation of his position and clarifying it—so that, hopefully, a useful/essential approach was not dismissed out of hand[25].

Hayes' response:

> It was worded in a barbed way, but I did (and do) mean it sincerely. But perhaps it can be misunderstood. Applied to Chris' application area, I did not mean to imply that every user in a large organization should invent their own metaphysics. I entirely agree that semantic consistency across large and varied datasets is valuable, perhaps essential. Someone has to provide a means to maintain this consistency, probably, in the current state of the art, by designing and publishing a common ontological framework and teaching people how to use it. My point was directed at the person to whom falls this responsibility, of designing and maintaining the central ontology. Should they feel that they need to study (or consult someone who has studied) metaphysics or philosophy before starting on this enterprise, or should they rather focus on making the ontology reflect the needs of their organization or community, and make up the 'metaphysics' as they go along, as much as seems necessary? I meant to suggest the latter[26].

Sowa does conclude with some reconciliatory remarks on the value of engaging both philosophical and scientific modes of inquiry:

> Although I have a high regard for some philosophy, I certainly do not genuflect to most of 20th century analytic philosophy, about which I would apply Mark Twain's remark about economics: "A philosopher's guess is liable to be as good as anybody else's."
>
> I did, however, learn a lot from those philosophers—not their conclusions, but how to do the analysis from more appropriate assumptions...
>
> I would consider any source as a place to look for ideas, but any ideas, new or old, must be tested against observation and experiment. The new medicines derived from ancient Chinese practice are good examples:

[25] Partridge (2007d).
[26] Hayes (2007g).

They're worth testing. Many of them fail the test, but some of them prove to be very effective[27].

[27]Sowa (2007d).

Appendix B

Document Formats—Supplementary Data

B.1 Sample Documents

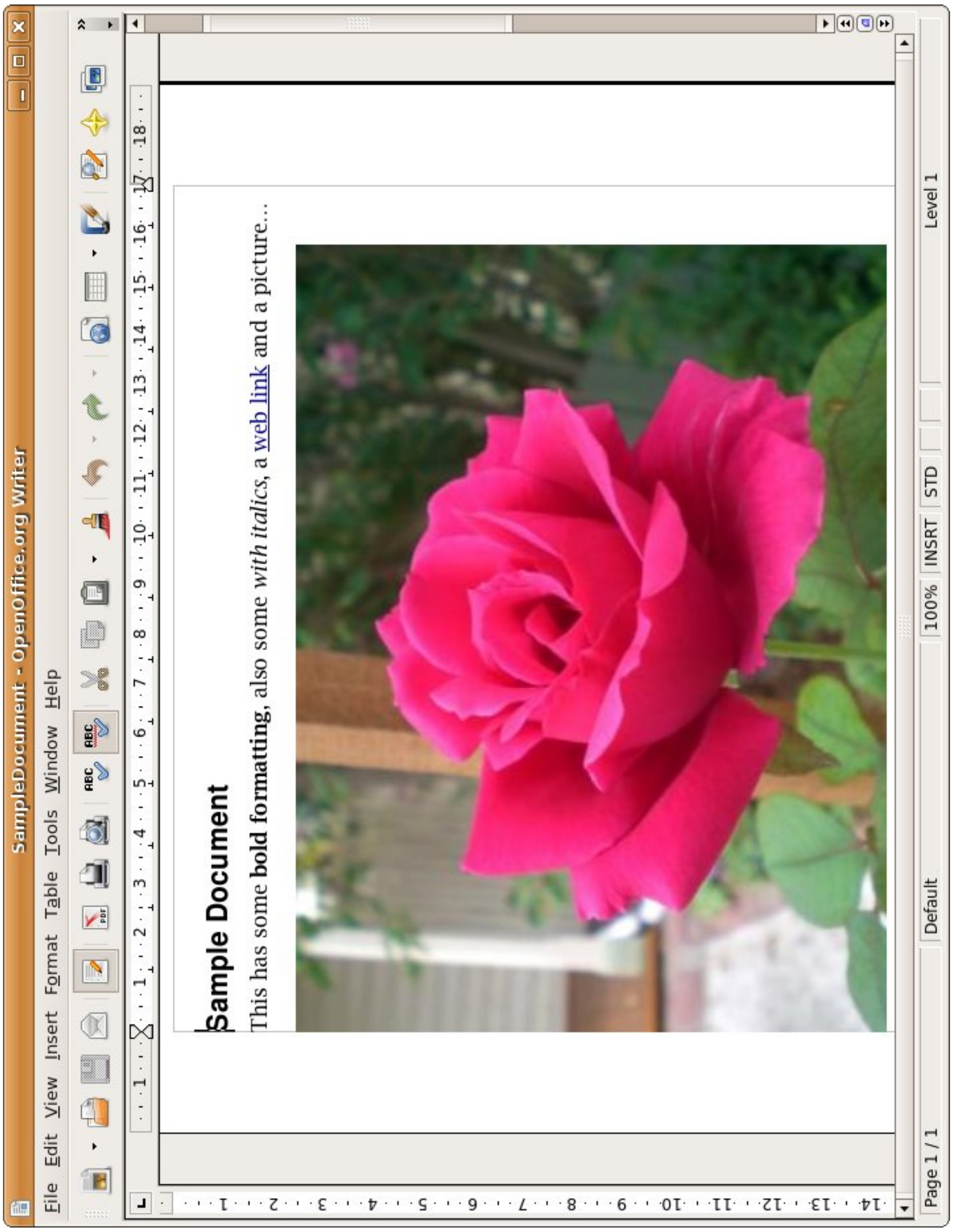


Figure B.1: The Sample Document in OpenOffice

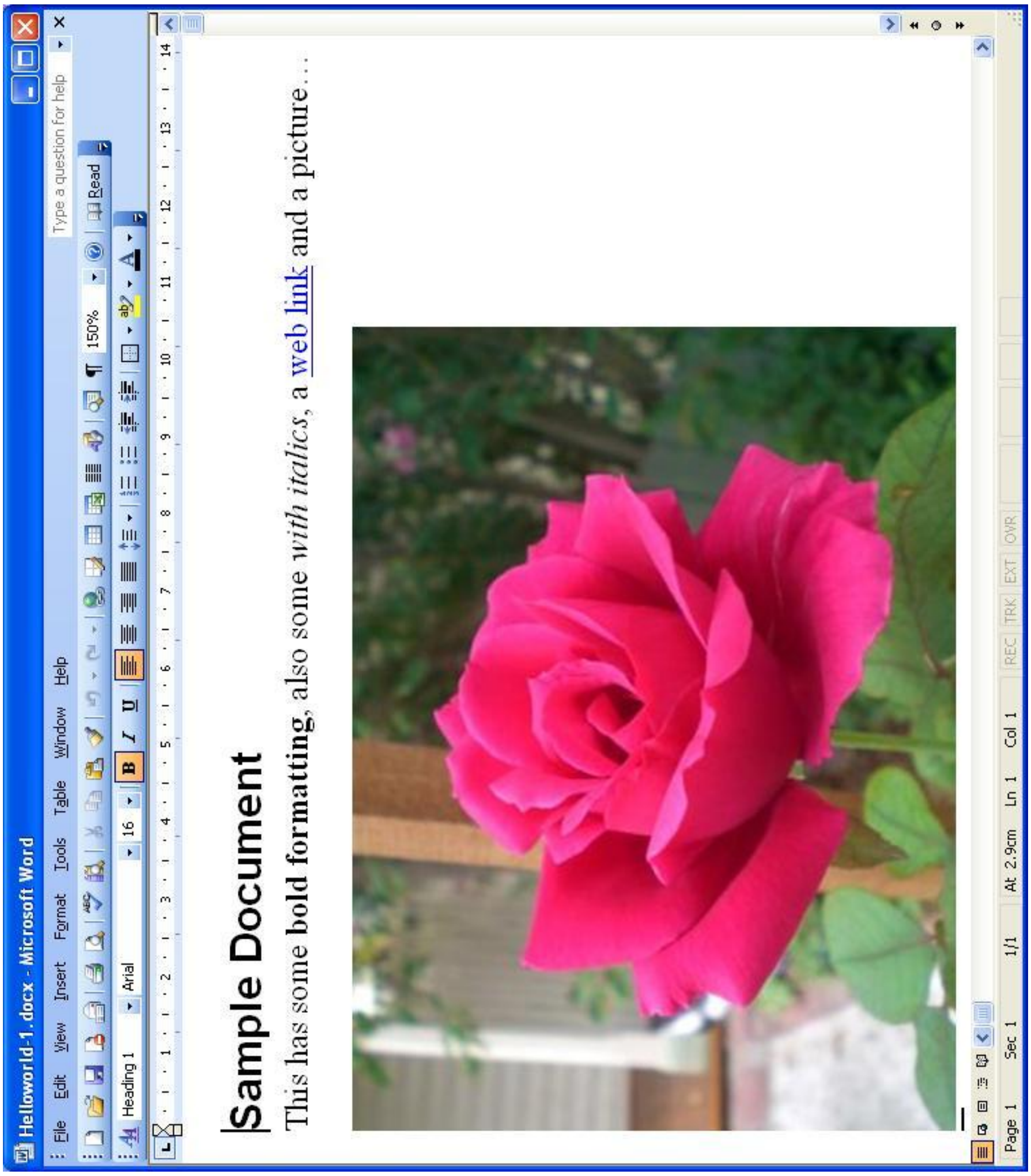


Figure B.2: The Sample Document in Microsoft Word

Appendix C

Framework in Practice—Supplementary Data

The following images depict screen shots of various parts of the Schema Profiling Toolkit, presented in Chapter 9.

C.1 Default Dimensions

Table C.1: The default dimension set—groups and dimensions.

Dimension Group	**Dimensions**	**Description**
Structure	• Small—Large • Self-contained—Derivative • Shallow—Deep • Sparse—Dense • Free—Restricted • Classificatory—Attributive • Literal-Object Composition • Qualitative—Quantitative • Lowly—Highly Annotated • Sparsely—Heavily Populated	Describes features inherent in the schema itself: whether it contains a relatively small or large number of entities, whether it uses predominantly classes or properties.

Table C.1: The default dimension set—groups and dimensions.

Dimension Group	**Dimensions**	**Description**
Semantics	• Simple—Complex • Specific—General • Intuitive—Obscure • Dispersed—Concentrated • Random—Coherent • Inaccurate—Accurate • Incomplete—Complete	Describes the relationship of the schema to things in the world: is it accurate? is it simple, intuitive, coherent, complete or otherwise in relation to the things it specifies?
Subject	• Concrete—Abstract • Spatial—Temporal • Natural—Social	Describes the subject matter of the schema (in general terms): is the subject matter concrete or abstract; predominantly spatial or temporal? is it about natural or social objects?
Style	• Light-hearted—Serious • Normative—Descriptive • Tentative—Committed	Describes the general manner in which the schema is written: is it light-hearted or serious in tone? does it mandate, or it is fairly open-ended and flexible? Is it speculative and suggestive or is it dogmatic about the terms it uses?
Process	• Lowly—Highly Representative of Users • Distributed — Central Design • Transparent — Closed Process • Informal — Formal Decision Making • Harmonious — Conflictual Design Process • Implicit — Explicit Assumptions • Ad Hoc — Rigorous Design Method	Describes how the schema has been developed: is it developed centrally (within an organisation for example), or in a distributed way? is the process open and transparent, and is a rigorous or ad hoc design method employed? are users well-represented in the design process? are the underlying assumptions behind the schema explicit?

Table C.1: The default dimension set—groups and dimensions.

Dimension Group	**Dimensions**	**Description**
Practice	• Small — Large Community • Low — Highly Active Community • Declining — Increasing Adoption Rate • Backwards Incompatible — Compatible • De Facto Standardisation • De Jure Standardisation • Low or High Industry Support • Low or High Availability of Documentation • Low or High Levels of Satisfaction • Recently published or mature	Describes how schema is used in practice: does it have a small or large community? is the community active, and is it increasing or declining? is the schema standardised in practice (de facto) or/and formally (de jure)? is there substantial support and documentation for the schema? is the schema mature, and is it broadly backwards-compatible with previous versions?
Purpose	• Low—High Social Motivation • Low—High Political Motivation • Low—High Economic Motivation • Low—High Scientific Motivation • Low—High Technological Motivation • Low—High Philosophical Motivation • Low—High Educational Motivation • Low—High Cultural Motivation • Low—High Legal Motivation • Low—High Environmental Motivation	Describes why the schema exists, in terms of various kinds of motivation: is it motivated by social, economic, political, technological or other kinds of reasons?

Table C.1: The default dimension set—groups and dimensions.

Dimension Group	**Dimensions**	**Description**
Perspective	• Every-day — Scientific • Pragmatic — Idealistic • Academic — Applied • Grounded — Speculative • Dependent — Independent	Describes the general orientation or perspective adopted by the schema: does it attempt to describe things in everyday or in scientific terms? is it pragmatic (grounded in current practical experience) or idealistic (promoting a new theory or classification, as yet untested)? is it heavily reliant upon viewpoints adopted in other schemas from which it is derived, or is it relatively independent?
Relationship	• Degree of conceptual overlap in domains • Degree of conceptual translation required • Logical consistency • Mutual awareness • Competitiveness • Commensurability of perspectives	Describe the relationships between two or more schemas: do they overlap significantly? are they aware of one another (either explicitly—through explicit references—or implicitly)? are they competitive? are they mutually consistent? are their overall perspectives commensurable?

C.2 Survey Results

Table C.2: Survey Results

Item	Count	Min	Max	Median	Mode	Chi-square
I am familiar with general data integration problems, technologies and approaches.	13	1	5	4	4	0.122
I am familiar with the Semantic Web and associated technologies (XML, RDF, OWL, SPARQL, etc.).	13	1	5	3	2	0.337
I am familiar with ontology matching concepts and approaches.	13	1	5	3	2	0.337
I found the model understandable and clear.	13	2	5	4	4	0.001
I found the model useful in the context of this project.	13	3	5	4	4	0.000
I think the model would useful for other projects.	13	2	5	4	4	0.085
I needed to modify the model to capture relevant dimensions (variables, properties) of the schemas I am comparing *.	13	2	3	3	3	0.000
I found the methodology clear, understandable and easy to apply.	13	2	5	4	4	0.001
I found the metholodology complex and confusing *.	13	1	4	3	2	0.040
I found the methodology useful for this project.	13	3	5	4	3	0.028
I think the methodology would be useful for other projects.	13	1	5	4	4	0.174
I found the analysis clear and understandable.	13	2	5	4	4	0.004
I found the analysis complex and confusing *.	13	1	4	2	2	0.040
I found the analysis useful for this project.	13	3	5	4	4	0.003

Table C.2: Survey Results

Item	**Count**	**Min**	**Max**	**Median**	**Mode**	**Chi-square**
I think the analysis would be useful for other projects.	13	2	5	4	4	0.004
I found the software intuitive and easy to use.	13	2	5	3	3	0.009
I found the software well documented.	13	2	5	4	4	0.040
I found the software useful for this project.	13	3	5	4	4	0.003
I think the software would be useful for other projects.	13	2	5	4	4	0.028
I think use of the toolkit would improve understanding of data schemas and ontologies.	13	3	5	4	4	0.000
I think the toolkit (and the associated conceptual framework) would be useful for data integration projects.	13	3	5	4	4	0.013
I think the toolkit would help reduce the time involved in data integration projects.	13	3	5	3	3	0.000
I think the toolkit would help reduce the costs of data integration projects.	13	3	5	4	3	0.006
I think the toolkit would help improve the accuracy of data integration projects.	13	3	5	4	4	0.013

* Indicates negatively-oriented items.

C.3 Schema Profiling Software

The following screen shots show the major steps in the evaluation process.

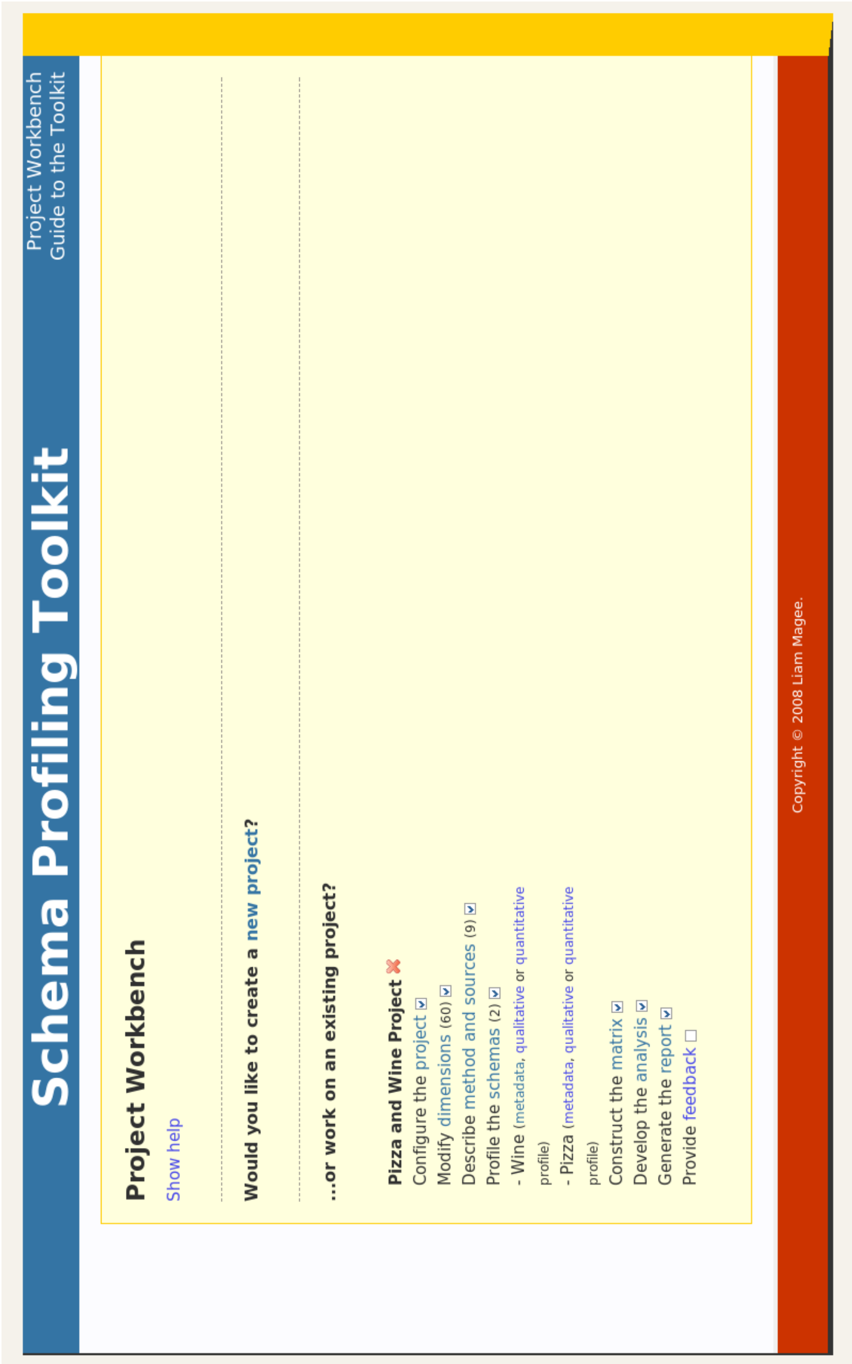


Figure C.1: Schema Profiling Software—Browsing Projects

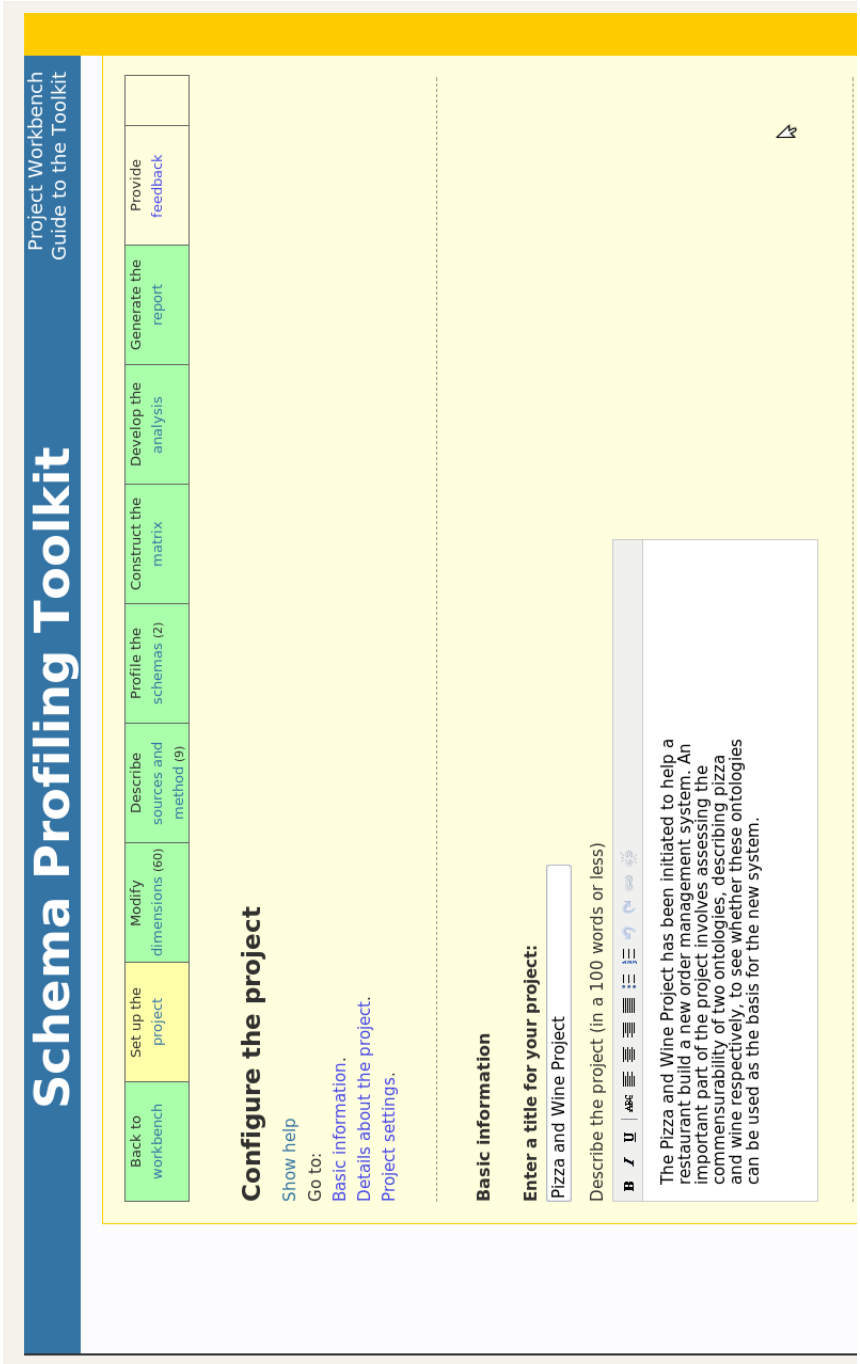


Figure C.2: Schema Profiling Software—Setting up the Project

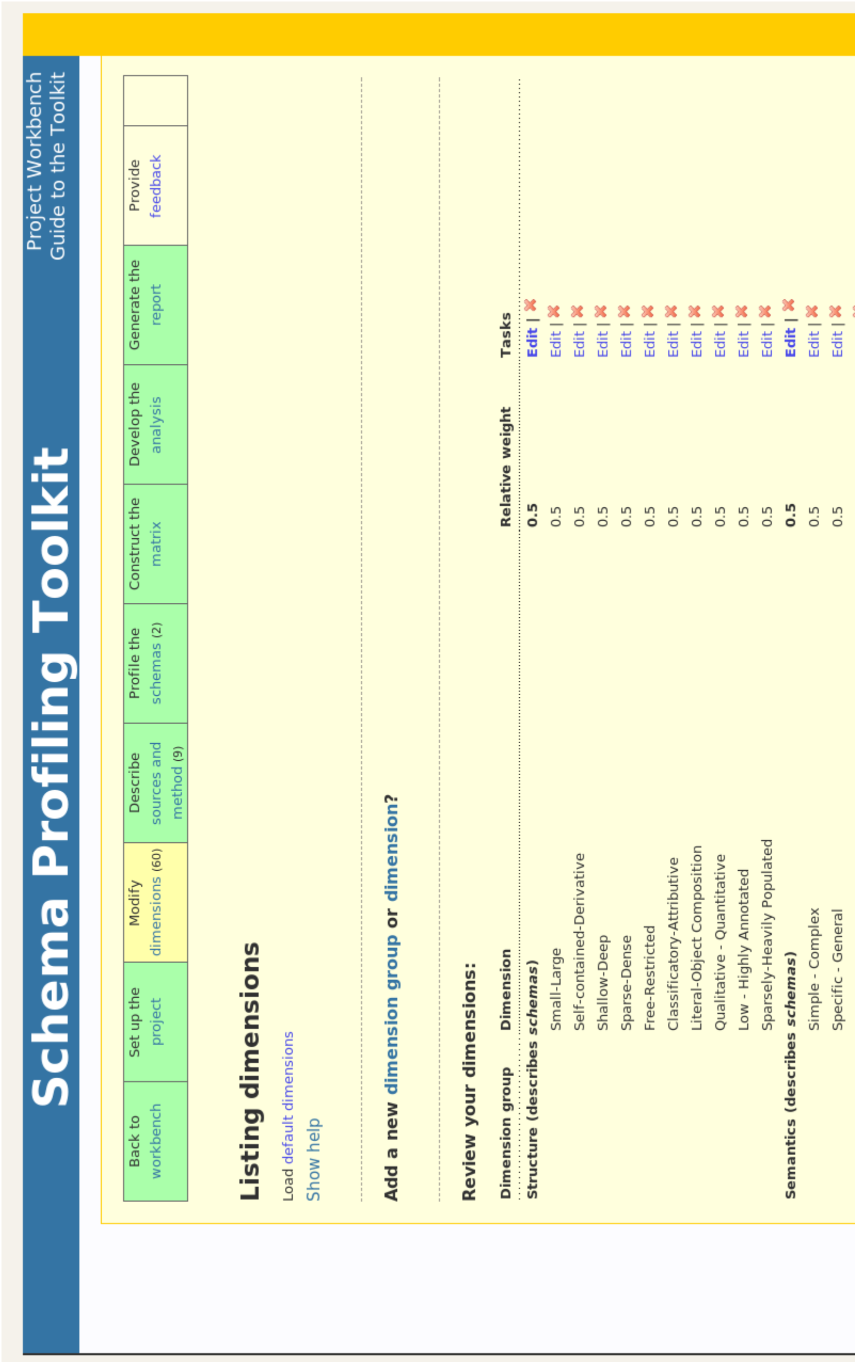


Figure C.3: Schema Profiling Software—Modifying the Dimensions

Figure C.4: Schema Profiling Software—Describing Method and Sources

Figure C.5: Schema Profiling Software—Profiling Schemas

Figure C.6: Schema Profiling Software—Constructing the Matrix

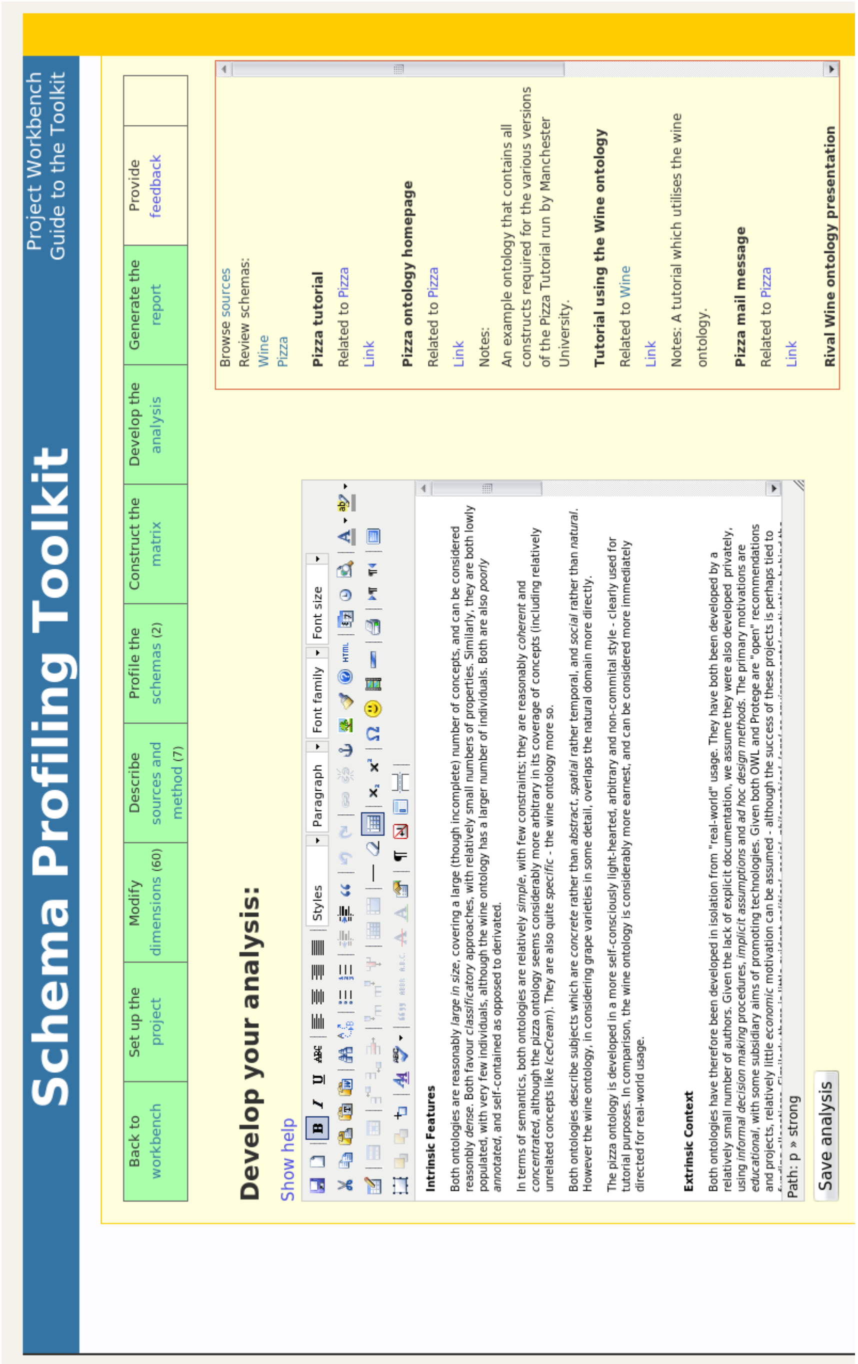


Figure C.7: Schema Profiling Software—Developing an Analysis

Figure C.8: Schema Profiling Software—Project Report

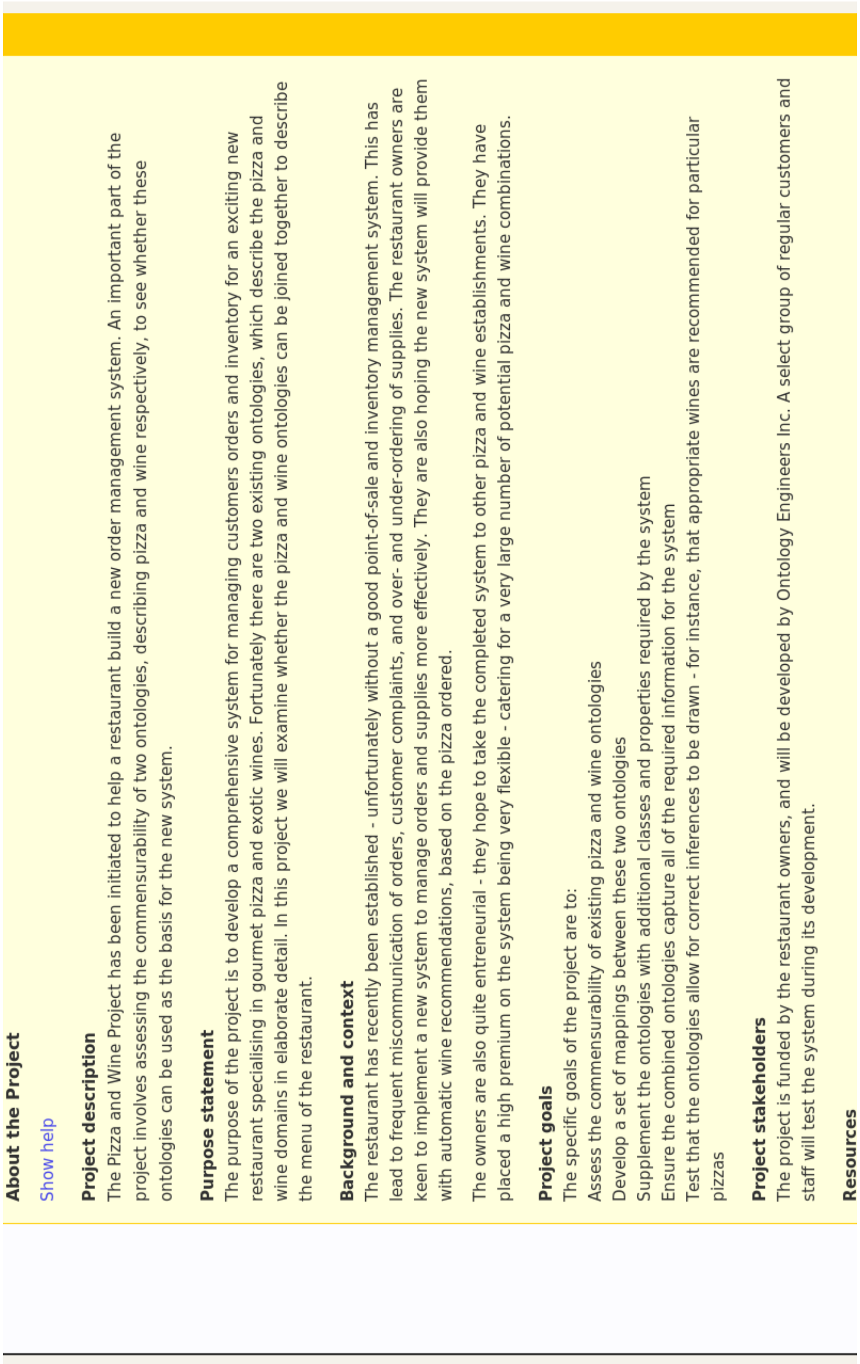
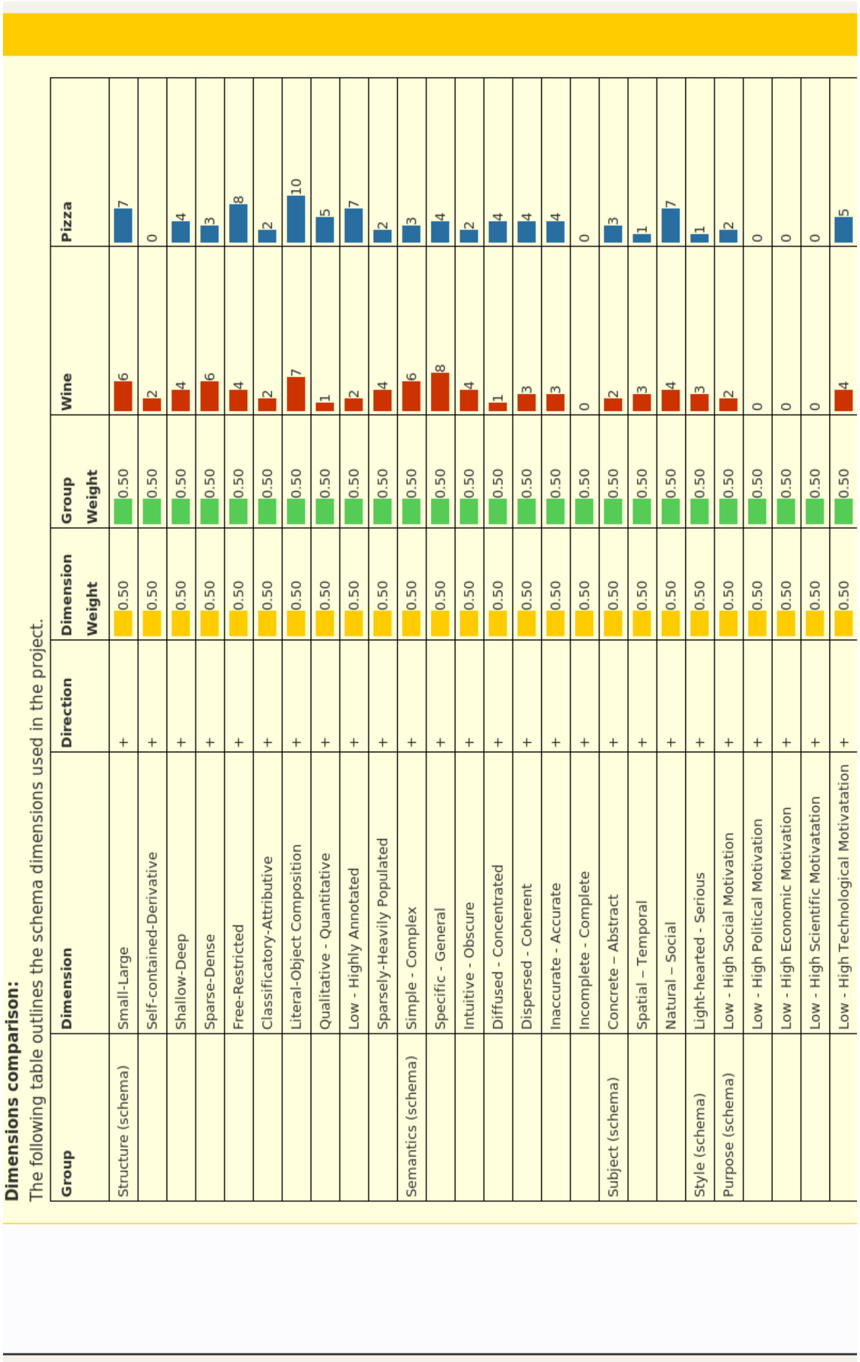


Figure C.9: Schema Profiling Software—Project Information

Qualitative Findings

Profile	Wine	Pizza
Structure	The Wine ontology imports and develops on a related Food ontology. It includes 162 individuals and 77 classes, but only a small number of properties.	The Pizza ontology is moderately sized, with 100 classes and a small number of properties and individuals. It does not import any other ontologies, and has a reasonable number of annotations.
Semantics	The Wine ontology classifies a broad range of wines as subclasses of a Wine class, which is itself classified as a Potable Liquid, which is in turn a Consummable Thing. Separate classes are defined for describing the wine colour and taste, and specifying the region, winery and vintage. These descriptions are connected by a dozen or so properties. For example, an instance of the Wine class can be described with 'hasMaker', 'hasVintageYear', 'hasBody' and 'locatedIn' properties. The authors have included types of grape, vintages, regions and specific kinds of wines as individuals. This has important implications: for the purposes of this project "individuals" refers to specific *bottles* of wine. The imported Food ontology has the concept of a MealCourse, which relates Wines with particular properties to various foods.	The Pizza ontology is predominantly class-based, and makes a high-level distinction between "DomainConcept" and "ValuePartition" classes. It is moderately complex, and quite specific, describing pizza toppings, bases and types in considerable detail.
Subject	The Wine ontology is about wine. It is fairly concrete, with a focus on wine locations. It focusses on the *natural* characteristics of wine - its grape, colour, region, etc. - as opposed to social characteristics (popularity, levels of consumption, taste qualities).	The Pizza ontology is about pizzas. It is quite concrete, and describes spatial types of things. Pizzas being human products, the ontology describes social objects.
Style	The Wine ontology is intended for tutorial purposes, so it is does not appear to aim to be a definitive or exhaustive list of wines, or ways of describing wines.	The Pizza ontology is developed in less-than-serious style. It enumerates a partial number of countries, non-pizza classes (IceCream), and values (spiciness). It seems purposely developed as a tutorial exercise, rather than a serious attempt to describe the domain.
Purpose	The Wine ontology has been developed as a guide to OWL and Semantic Web ontologies. It therefore has a *social* and *technological* motivation (of teaching), rather than any obvious other motivation. From appearances, the purpose of the ontology is to provide a clear example of an ontology based on real-world requirements.	The purpose of the ontology is to educate users about ontologies - the main motivations are therefore social and technological.
Process	It is not clear how the system was developed, but it appears to be developed privately by the authors.	It is assumed the ontology is developed privately, in a closed proced, with an informal decision-making and ad-hoc design process. The assumptions are not explicit. However no documentation is available outlining the development process.
Practice	The ontology is presumably used by people wanting to learn about	The ontology is used to educate users in how to develop ontologies and

Figure C.10: Schema Profiling Software—Qualitative Comparison



Dimensions comparison:
The following table outlines the schema dimensions used in the project.

Group	Dimension	Direction	Dimension Weight	Group Weight	Wine	Pizza
Structure (schema)	Small-Large	+	0.50	0.50	6	7
	Self-contained-Derivative	+	0.50	0.50	2	0
	Shallow-Deep	+	0.50	0.50	4	4
	Sparse-Dense	+	0.50	0.50	6	3
	Free-Restricted	+	0.50	0.50	4	8
	Classificatory-Attributive	+	0.50	0.50	2	2
	Literal-Object Composition	+	0.50	0.50	7	10
	Qualitative - Quantitative	+	0.50	0.50	1	5
	Low - Highly Annotated	+	0.50	0.50	2	7
	Sparsely-Heavily Populated	+	0.50	0.50	4	2
Semantics (schema)	Simple - Complex	+	0.50	0.50	6	3
	Specific - General	+	0.50	0.50	8	4
	Intuitive - Obscure	+	0.50	0.50	4	2
	Diffused - Concentrated	+	0.50	0.50	1	4
	Dispersed - Coherent	+	0.50	0.50	3	4
	Inaccurate - Accurate	+	0.50	0.50	3	4
	Incomplete - Complete	+	0.50	0.50	0	0
Subject (schema)	Concrete – Abstract	+	0.50	0.50	2	3
	Spatial – Temporal	+	0.50	0.50	3	1
	Natural – Social	+	0.50	0.50	4	7
Style (schema)	Light-hearted - Serious	+	0.50	0.50	3	1
Purpose (schema)	Low - High Social Motivation	+	0.50	0.50	2	2
	Low - High Political Motivation	+	0.50	0.50	0	0
	Low - High Economic Motivation	+	0.50	0.50	0	0
	Low - High Scientific Motivatation	+	0.50	0.50	0	0
	Low - High Technological Motivatation	+	0.50	0.50	4	5

Figure C.11: Schema Profiling Software—Dimension Data Values

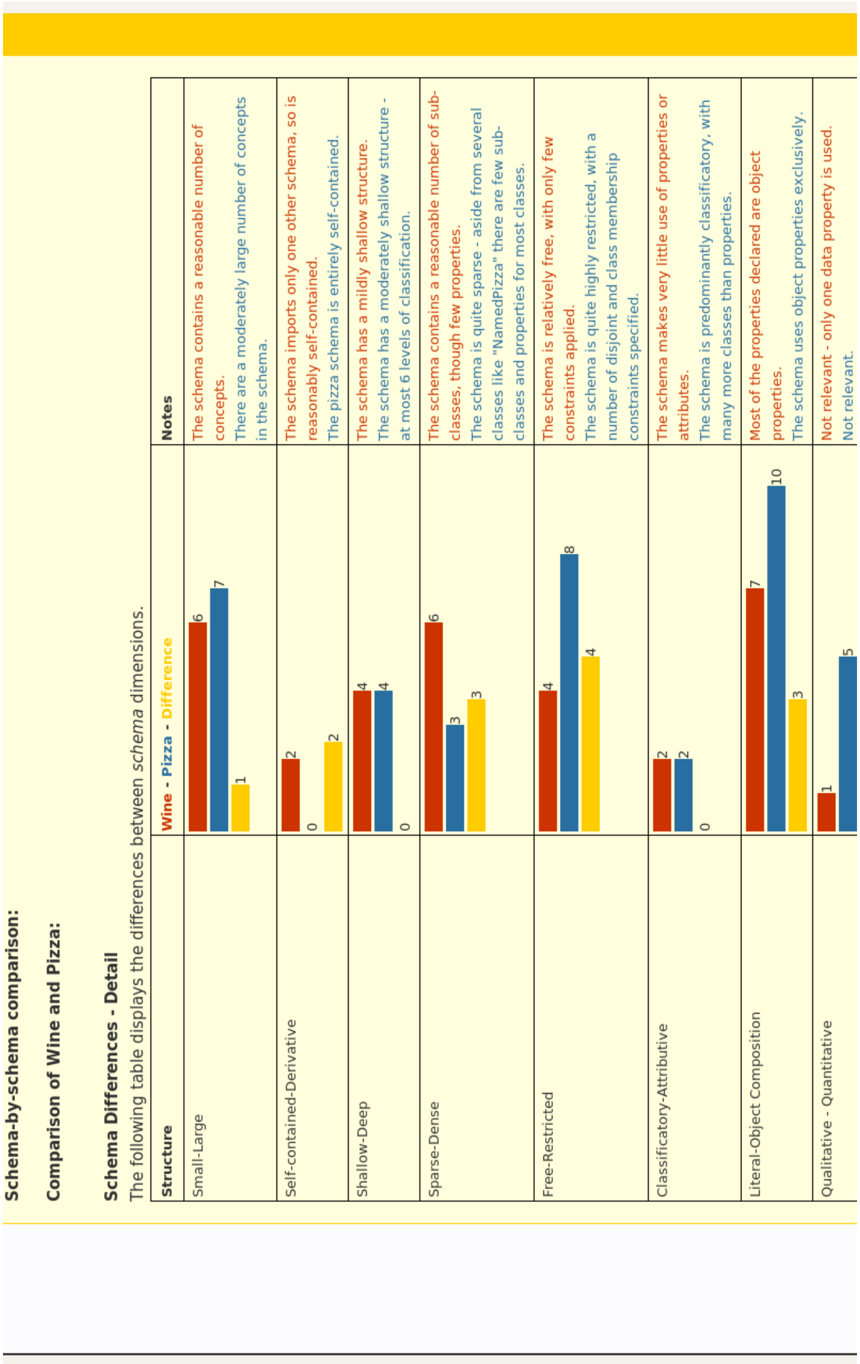


Figure C.12: Schema Profiling Software—Schema Comparison

Average	**1.40**
Weighted Average	**1.40**

Overall Commensurability Ratings

The following table displays the following *overall* average commensurability ratings between the Wine and Pizza schemas:

- Normal (unweighted) averages
- Averages weighted by the *dimension* weights
- Averages weighted by the *dimension group* weights
- Averages weighted by the *dimension* and *dimension group* weights

Schema Commensurability Rating	**Average Commensurability Value**
Average:	1.81
Weighted Average:	1.81
Weighted Group Average:	1.88
Weighted Group and Dimension Average:	1.88
Relationship Commensurability Rating	**Average Commensurability Value**
Average:	1.40
Weighted Average:	1.40
Weighted Group Average:	1.40
Weighted Group and Dimension Average:	1.40
Overall Incommensurability Rating	**Commensurability Value**
Average:	1.60
Weighted Average:	1.60
Weighted Group Average:	1.64
Weighted Group and Dimension Average:	1.64

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Figure C.13: Schema Profiling Software—Overall Commensurability Ratings

Figure C.14: Schema Profiling Software—Submitting Feedback

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